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METHODS FOR PULP AND PAPER MILL SLUDGE UTILIZATION AND DISPOSAL

Thomas R. Aspitarte, et al

Crown Zellerbach Corporation

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16. Abstract

The disposal of pulp and paper mill sludge in a manner which has minimal effect on the environment has become a serious problem. ~~This project was carried out to evaluate~~ four methods of disposal were evaluated, namely: (1) incineration in an air entrained dryer-incinerator, (2) burning in hog fuel boilers, (3) incorporation into soil as an amendment, and (4) hydromulching for soil stabilization. Other possible uses are discussed. Burning sludge in incinerators costs between $11 and $13/dry ton, including all prior dewatering steps. Sludge can be made available at various degrees of dewatering at costs of from $7 to $20/dry ton. Incorporation into farm soil offers the possibility for disposal of large quantities of sludge. At low levels (100-200 tons/acre) crop yields are satisfactory, provided adequate nitrogen is added. A high level incorporation (600 tons/acre) requires a year of fallow preceding crop planting. Sludge alone or in combination with bark can be used as a hydromulch in establishing grass stands on steep embankments. (EPA)

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METHODS FOR PULP AND PAPER MILL SLUDGE UTILIZATION AND DISPOSAL

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ABSTRACT

Many pulp and paper mills are now faced with a serious problem in disposal of primary treatment plant sludge. The system selected by mills for sludge disposal or utilization must be one that has a minimal overall impact upon the environment.

The original project was designed to evaluate four methods by which such fibrous sludge may be utilized. These methods of sludge disposal were: (1) incineration in an air entrained dryer-incinerator, (2) burning in hog fuel boilers, (3) incorporation into soil as an amendment, and (4) hydromulching for soil stabilization.

During the course of this study, other possible uses for sludge were suggested and investigated. This report therefore includes data from such experimental observations.

Disposal of sludge in incinerators or hog fuel boilers will cost between $11 and $13/dry ton. At the mill site sludge could be made available for other means of disposal at costs between $7 and $20/dry ton, depending on the degree of dewatering and form in which it would be handled.

Incorporation of sludge in farm soil was found to be an excellent method for disposal of large quantities of sludge. In combination with crop production, however, certain problems could arise. At high levels, such as 600 tons per acre, a year fallow appears necessary in order to obtain significant increases in crop yield. Crop yields in fresh mixtures of low sludge levels and soil were satisfactory provided adequate nitrogen was added.

Sludge alone or in combination with bark was competitive as a hydromulch material in establishing grass stands on steep embankments.

This report was submitted in fulfillment of Project 12040 ESV under the partial sponsorship of the Environmental Protection Agency, in cooperation with Crown Zellerbach Corporation, Camas, Washington.

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SECTION I

CONCLUSIONS

1. Sludge properties vary considerably, but can be characterized for disposal by frequent samplings and tests such as Canadian standard freeness, ash content and fiber size distribution (fiber fractionation). Generally, all relate to the types of pulps and paper products being manufactured. Elemental analyses of the ash reveal that the inorganic portion of the sludge originates from clay, silt, and sand, carried by wood mill effluent, and from various additives required for paper making.

2. Disposal of primary treatment plant sludge from an integrated pulp and paper mill can be accomplished by an air-entrained incinerator. Over a 3 year period, operating costs for incinerating sludge were $9.78-11.68 per ton for a 20,000 ton/year plant. Plant capital cost (1968-1969 basis) was $350,000. Total disposal costs, including primary treatment (clarifier and filter operation) were $12.84-14.60/ton. Maintenance cost was almost 1/3 the operating cost. Tests show that the system can meet air pollution standards for a waste material incinerator with a wet fan-type dynamic scrubber made of stainless steel. Material balance data around a sludge dewatering device requires frequent measurements of consistencies and the measurement of one flow to or from the device.

3. Pressed and fluffed primary treatment plant sludge can be burned in a steam generating boiler with hog fuel. There should be minimum effects on the operation if sludge content of the fuel mix is no more than 5%. Reduction in thermal efficiency of the boiler is related to the higher ash content and lower calorific fuel value (of the organic portion) of sludge, both compared to hog fuel. There would be an approximate $1.50/ton savings by burning sludge in a hog fuel boiler over burning it in a separate incinerator with no heat recovery. Part of this savings could be offset because the boiler would have to be cleaned more often, due to ash accumulation.

4. From a primary treatment plant, sludge can be prepared for disposal as a dewatered material at about 20% solids content, or as a pressed material at about 38% solids content. Semi-drying sludge to 77% solids, followed by baling, densifies the sludge to about 34 lb dry material/cu ft. This is triple the solids density of either dewatered or pressed sludge.

The cumulative costs per dry ton of sludge for dewatering, pressing, semi-drying and baling are respectively $3.06, $7.38, $13.86 and $19.89.

Hauling costs are dependent upon hauling distance, sludge consistency and method of transport. Such costs were found to vary from $14-17/dry ton for hauling bulk, pressed and fluffed sludge a short distance to $49/dry ton to haul the same type of sludge about 250 miles by truck. These costs do not include selling costs, profit or special handling charges.

5. Soil respirometer experiments showed that extensive sludge breakdown was obtained when levels of sludge were added to nitrogen containing clay soil. In nitrogen deficient sandy soils supplemental nitrogen was necessary to obtain significant sludge decomposition. Additional nitrogen was needed in both soils to optimize sludge utilization when high levels of sludge were added.

6. Sunflower plant growth responses in sandy and clay soils amended with sludge and nitrogen were studied in greenhouse experiments. Amendments of sludge and nitrogen improved sandy soil more than clay soil as shown by increased sunflower yield. For example addition of 100 tons/acre (T/A) sludge to clay soil with supplemental nitrogen caused a 1.7 fold increase in sunflower yield. With sandy soil the same treatment resulted in a 2.7 fold increase in yield.

7. Large amounts of sludge were readily degraded by mixing into soil. After three years decomposition, plot levels decreased from the initial two foot level to a level almost equal to control plots not receiving sludge. Volatile solids and improvement in yields of corn and beans were obtained with high sludge incorporations which were evaluated under the tolerance design. Amendments of 100 and 200 T/A did not adversely affect corn and bean yields the following crop season provided supplemental nitrogen was added to satisfy both plant and microbial requirements. When 400 and 600 T/A sludge additions were allowed to decompose without supplemental nitrogen for at least a year, test crops showed increased yield, earlier maturation and reduced irrigation requirements.

8. Grass plantings by the hydromulch process indicate that pulp and paper mill sludge or a mixture of sludge and bark is equivalent to the wood fiber product currently used as a mulching agent. The lower freeness or drainage rate of sludge over wood fiber allows application to be made at a higher solids content. The cost of a delivered semi-dried bale of sludge in a local area should make sludge or sludge-bark mixtures competitive products.

9. Hydromulching and bulk mulching of raspberries, strawberries and tomatoes caused a reduction in weed activity. However, with increases in sludge depth, decreases in crop yield were observed.

10. Morel mushrooms well in excess of natural occurrence were observed growing on various sludge amended plots in the spring of 1971 and 1972. All attempts to grow these mushrooms by design were unsuccessful.

11. Dried, oil-treated sludge can be used as an oil absorbing material for oil spill clean up. However, on basis of cost and storage problems, it does not appear competitive with other marketed materials.

12. Sludge was not toxic to ruminants when used as a feed supplement at levels up to 15% of the grain ration. It has a very low feeding value since the test steers were observed to lose more weight as the percentage of sludge was increased in place of corn.

13. Dried sludge has application as a bedding material for dairy cattle. It readily absorbs liquids and is competitive to shavings which are becoming increasingly more costly and difficult to obtain.

14. Sludge-perlite (1:3) and sludge-vermiculite (1:1) mixtures were satisfactory potting media for containerized production of several plant species. Douglas fir responded well in a mixture of equal portions of sludge and bark. All two-component sludge mixtures were noticeably improved as potting media with addition of river sand.

Root knot nematode galls on tomato transplants were markedly reduced by incorporation of sludge in nematode infested soil at rates equivalent to 100 and 200 T/A.

SECTION II

RECOMMENDATIONS

High maintenance costs in the incinerator were caused by the abrasive action of high ash content sludge on various pieces of equipment and ducting. To reduce these costs, affected areas in equipment should be modified or made more resistant to this abrasive action. Reduction of abrasive material may be accomplished by treatment of effluents containing high levels of inorganics. Consideration may also be given to the development of high volume centrifugal cleaners for de-ashing effluents or high consistency cleaners for processing low consistency sludge.

Disposal of large quantities of sludge was found to be feasible under field conditions in a clay soil. Similar evaluation is needed in sandy soils to not only determine increase in soil productivity and tilth, but to also study sludge effect on water retention and sand stabilization.

Preliminary experiments on use of sludge as a cattle bedding material showed promise. There is a potential use of sludge as bedding in place of more expensive and less available wood shavings. The possibility of using sludge as a poultry litter absorbent has been suggested and requires evaluation.

The proliferation of edible "morels" in sludge amended plots was found to be extremely interesting. Answers to cause could easily found an industry for growing morels which to date have not successfully been artificially produced.

Major utilization of sludge would result from development of sludge containing "synthetic soils" for use in containerized crop production. Favorable results obtained in greenhouse studies show potentiality for sludge use in soil mixes. Future work should include evaluation of various synthetic mixes and test species representing the spectrum currently grown in containers.

Observed control of root-knot nematode by sludge incorporation indicates need for further and more extensive study. Sludge additions to soil containing other soil borne parasites or pathogens may be worthy of investigation.

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SECTION III

INTRODUCTION

Most pulp and paper mills in the United States today provide primary treatment for the removal of settleable solids from their effluents. Disposal of the resultant solids presents a problem facing the industry.

Initially, land storage and land fill within a short distance of the mill were used for sludge disposal. However, since the material dried and decomposed slowly, this approach at best was only a temporary expedient. Although by-product utilization presents some possibilities, contamination and extreme variability of product mitigates against extensive development of markets.

Burning of sludge in hog fuel power boilers is being practiced at a number of mills, but there is little reported data and information on this method. Information on the effect of sludge upon steam generation and atmospheric emissions has not been available. Burning of sludges in specially designed incinerators is widely used for domestic wastes and is used at several paper mills (1).

Sludge utilization as an agricultural amendment presents a potential for large scale sludge disposal either by incorporation into the soil or as a mulching material. Since many pulp and paper mills are located in areas accessible to rather large tracts of suitable agricultural land, development of this disposal method appears to have considerable merit.

Early in 1968 Crown Zellerbach Corporation received a research and development grant from the Environmental Protection Agency for a project to be conducted at the company's Camas Mill. The study was designed to study four different methods of sludge disposal with the objective of obtaining sufficient information and data for the design of full scale disposal systems. The methods of sludge disposal investigated and reported in this paper were: (1) incineration in an air entrained dryer-incinerator, (2) burning in hog fuel boilers, (3) incorporation into soil as an amendment, and (4) hydromulching for soil stabilization.

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SECTION IV

SLUDGE CHARACTERISTICS

In considering the various possibilities for disposing of pulp and paper mill primary treatment plant sludge, the properties related to disposal should be characterized. Basically, the sludge is a fibrous material, and so Canadian standard freeness, ash content, and fiber size distribution (fiber fractionation) are logical properties to evaluate. The various strength tests, associated with pulp and paper making fibers, would only have meaning if the sludge were screened and cleaned. In this case, the sources contributing to the sludge and the type of mill generating the material would affect the feasibility of fiber recovery. Source of sludge for this project is an integrated pulp and paper mill, producing bleached kraft and sulfite grades. Table 1 gives average sludge properties, taken during five different sampling periods.

During 1968, samples were taken of the primary treatment plant coil filter cake, going to land fill. This was prior to the building of the air-entrained incinerator. These sludges could be characterized by high ash, low freeness, and high amounts of -150 mesh size solids. Improvements in the wood mill effluent grit collector and diversion of a mill parking lot storm sewer into a city storm sewer lowered the ash content, raised sludge freeness, and lowered the amount of -150 mesh solids. The range of property values has also tended to decrease over the period of treatment plant operation. This is somewhat evident in the range of ash content values shown in Table 2.

Again referring to the previous table, the data do show that removing wood mill effluent from the primary treatment plant causes a decrease in ash content. A special project done by the mill indicated that almost 1/2 of the ash in the sludge comes from the wood mill. Also, about 70% of the grit, or abrasive material in sludge ash, is from wood mill effluent. The elemental analyses of sludge ashes were determined spectrographically by the State of Oregon, Department of Geology and Mineral Resources and are shown in Table 3.

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TABLE 1

AVERAGE SLUDGE PROPERTIES--VARIOUS SAMPLINGS

Sample Date	Canadian Standard Freeness, cc	% Ash, O.D. Basis	Fiber Fractionation, % on Mesh					
			14	20	35	65	150	-150
Feb.-Mar., 1968*	209	26.5	9.6	7.8	10.4	9.3	8.0	54.9
June-July, 1968**	370	29.7	10.4	8.9	9.4	7.9	8.1	55.3
Aug. 4, 1970	380	17.4	12.6	11.9	12.1	9.6	7.6	46.2
Sept. 13-15, 1971	621	20.7	13.7	11.1	10.4	7.4	9.8	47.6
Nov. 25-Dec. 26, 1972	556	19.0	19.6	10.7	10.9	10.6	9.4	38.8

*Average of 54 samples of filter cake.

**Average of 28 samples of filter cake.

TABLE 2

ASH CONTENT OF SLUDGE SAMPLES

Sample Source, Number, Period	% Ash, O.D. Solids Basis		
	Average	Minimum	Maximum
Filter Cake, 54, 2/1/68-3/17/68	26.5	10.3	55.1
Filter Cake, 28, 6/5/68-7/2/68	29.7	15.5	41.3
Press Cake, 25, 4/1/70-6/23/70	26.5	19.6	35.4
Press Cake, 5, 8/17/70-8/21/70*	18.5	16.5	22.4
Press Cake, -,** 9/13/71-9/15/71	20.7	--	--
Press Cake, 12, 11/25/72-12/6/72	19.00***	--	--

*Wood mill effluent diverted to alternate settling pond.

**Composite of samples taken over the period.

***Samples composited for ash determination.

TABLE 3

ELEMENTAL ANALYSIS OF ASH SAMPLES

Sample Source and Date	Over 10%	1%-10%	0.1%-1%	0.01%-0.1%	0.001%-0.01%	Below 0.001%
Coil Filter - 2/1/68-3/17/68	Si	Al, Fe, Na, K Ti	Mg, Mn	Pb, Ba, Sr	Zr, Sn, Cr, Cu, Ni, B	--
Coil Filter - 6/5/68-7/2/68	Si	Al, Fe, Ca, Na, K, Ti	Mg, Mn	Ba, Pb, Sr	Zr, Cr, Mo, Cu, Ni, B	--
Press Cake - 4/1/70-6/23/70	Si, Al	Fe, Mg, Ca, Na, Ti	K	Mn, Pb, Cu, Ba, Sr	Zr, Cr	Ni

The high amounts of silicon, aluminum, potassium, and iron would confirm the presence of mud, clay, and silt brought in with logs to the wood mill. They enter the effluent from the log washing and hydraulic barking systems. Much of the inorganics originate from materials, such as alum, clay, silicate, and other additives, used in various specialty grades in the paper mill. Summarily, the type of operations carried on by the mill will affect sludge properties.

SECTION V

INCINERATION--AIR ENTRAINMENT

The EPA grant to Crown Zellerbach Corporation shared in the expense of building an air-entrained incineration plant for the disposal of sludge from the Camas pulp and paper mill primary treatment plant. The existing facility consisted of a 330 ft diameter clarifier which delivers an underflow sludge at 2-6% solids content to two 11 ft diameter by 10 ft wide coil filters. These further dewater the sludge to 18-22% solids. Prior to building the disposal plant, the filter solids were conveyed to land fill. Figure 1 shows the original primary treatment plant and Figure 2 shows the air-entrained incinerator.

The air-entrained system flow sheet, shown in Figure 3, starts with a V-type press which expels liquid from the sludge to increase the solids content to 37-40%. The pressate liquid is returned to the clarifier. From the top of the press, the press cake is discharged to a screw conveyor which transports it to a fluffer. This is a high speed hammer mill which breaks up the cake for better drying and incineration. Material then drops into the hot gas stream from the incinerator to be carried up through the dryer. This is a vertical conical shaped vessel with two necked-in sections in the upper part. In each of the sections there is a velocity control cone on a central shaft which can be raised or lowered to alter velocity and retention time in the dryer. Dried material and conveying gas are separated in a cyclone. The gas is drawn through all this process by a large induced draft fan. Water is sprayed into the fan to scrub particulate, and then the water containing particulate, is separated from the gas in a cyclone. Gas is discharged to the atmosphere.

Dried material at 70-85% solids content drops out of the cyclone through a rotary air lock valve into a stream of conveying air. This stream carries the sludge into the upper part of the cylindrical shaped incinerator where it enters centrifically and burns. Natural gas is burned with its own combustion air in the lower part to heat up the incinerator on start-up. When sufficient heat is generated from sludge combustion to support burning (autogenous reaction), then gas use is limited to maintaining burner control only. At times, gas is burned to furnish supplementary heat if the fuel value of the sludge

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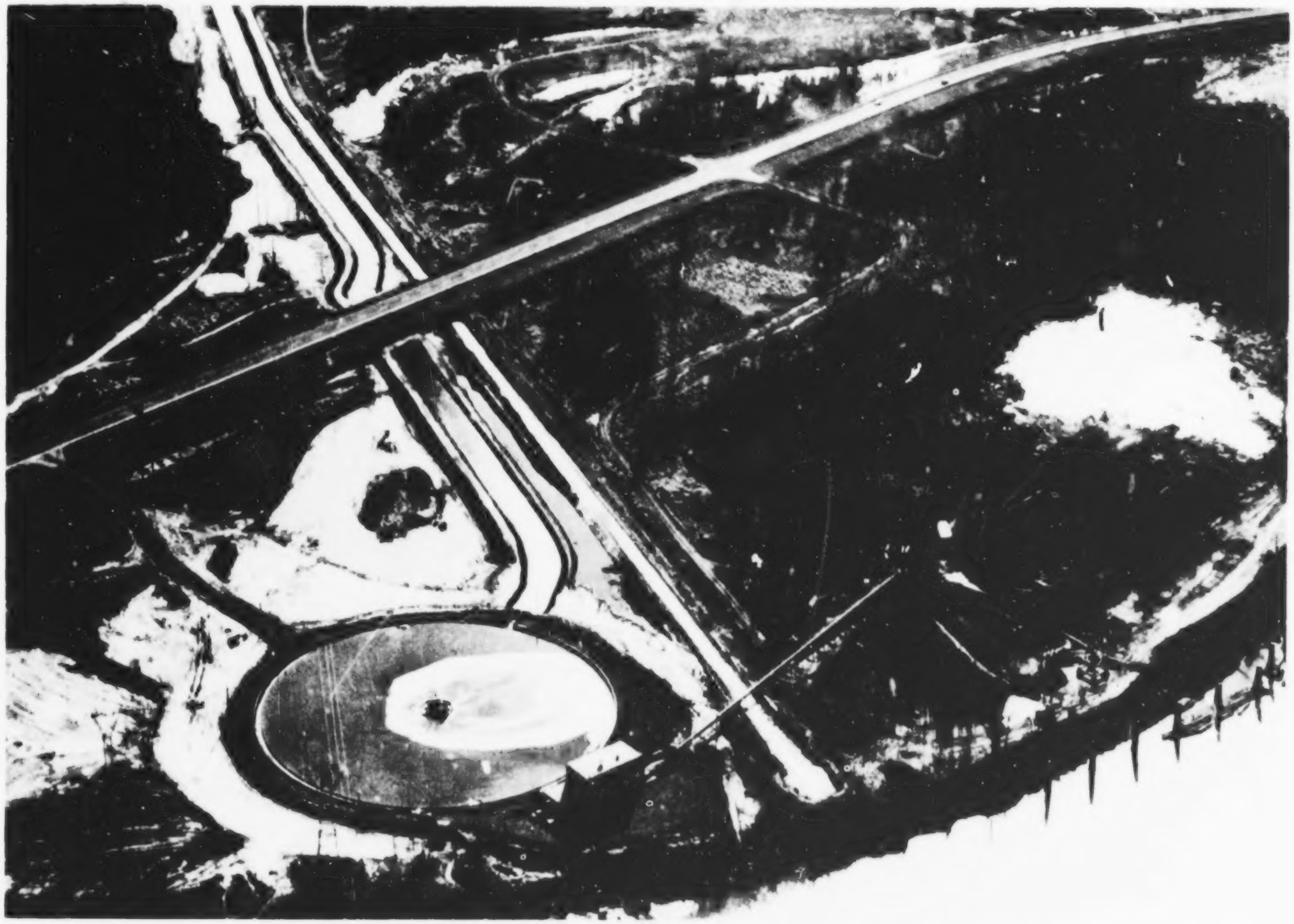


FIGURE 1. PRIMARY TREATMENT PLANT SHOWING SLUDGE DISPOSAL AREA.

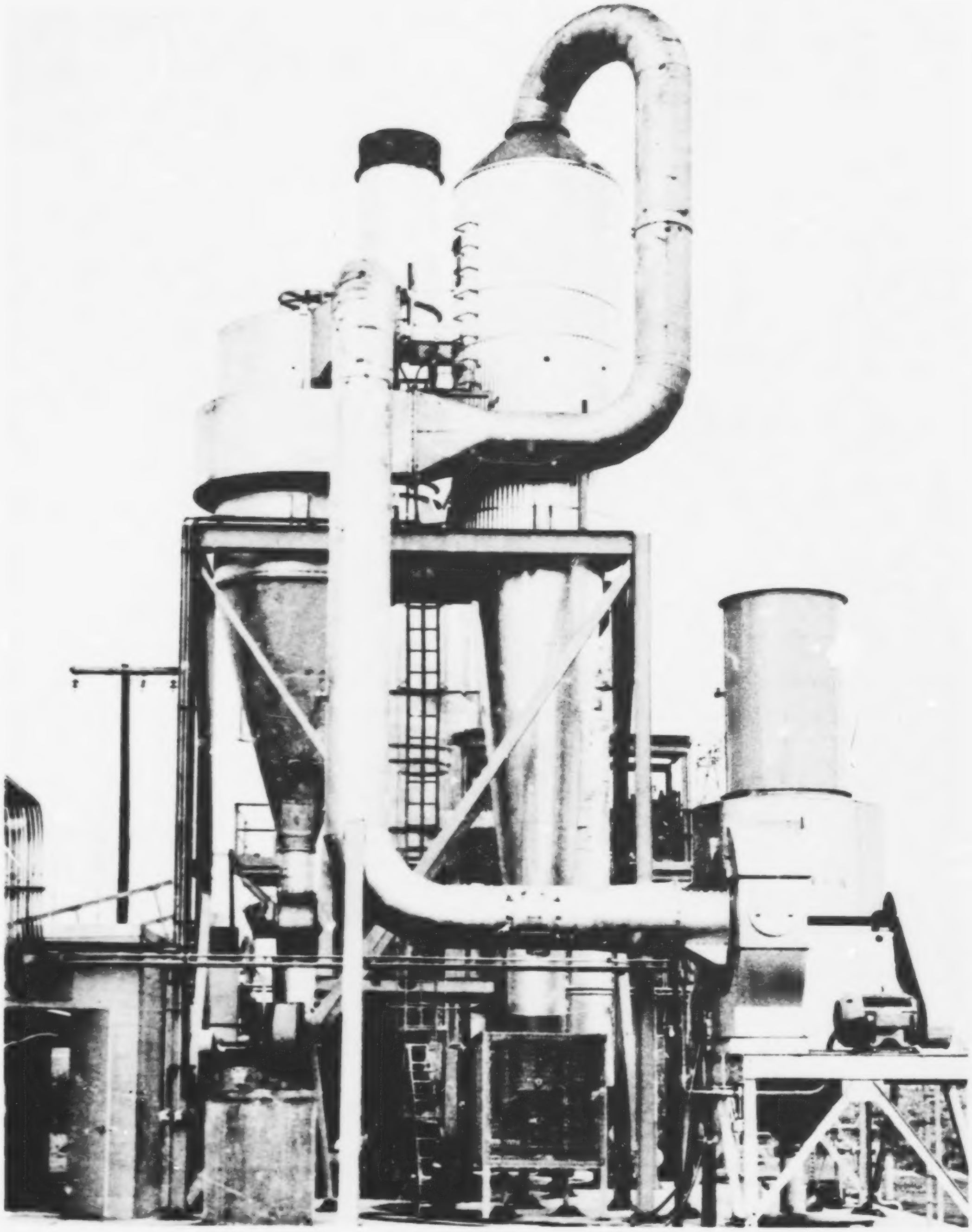
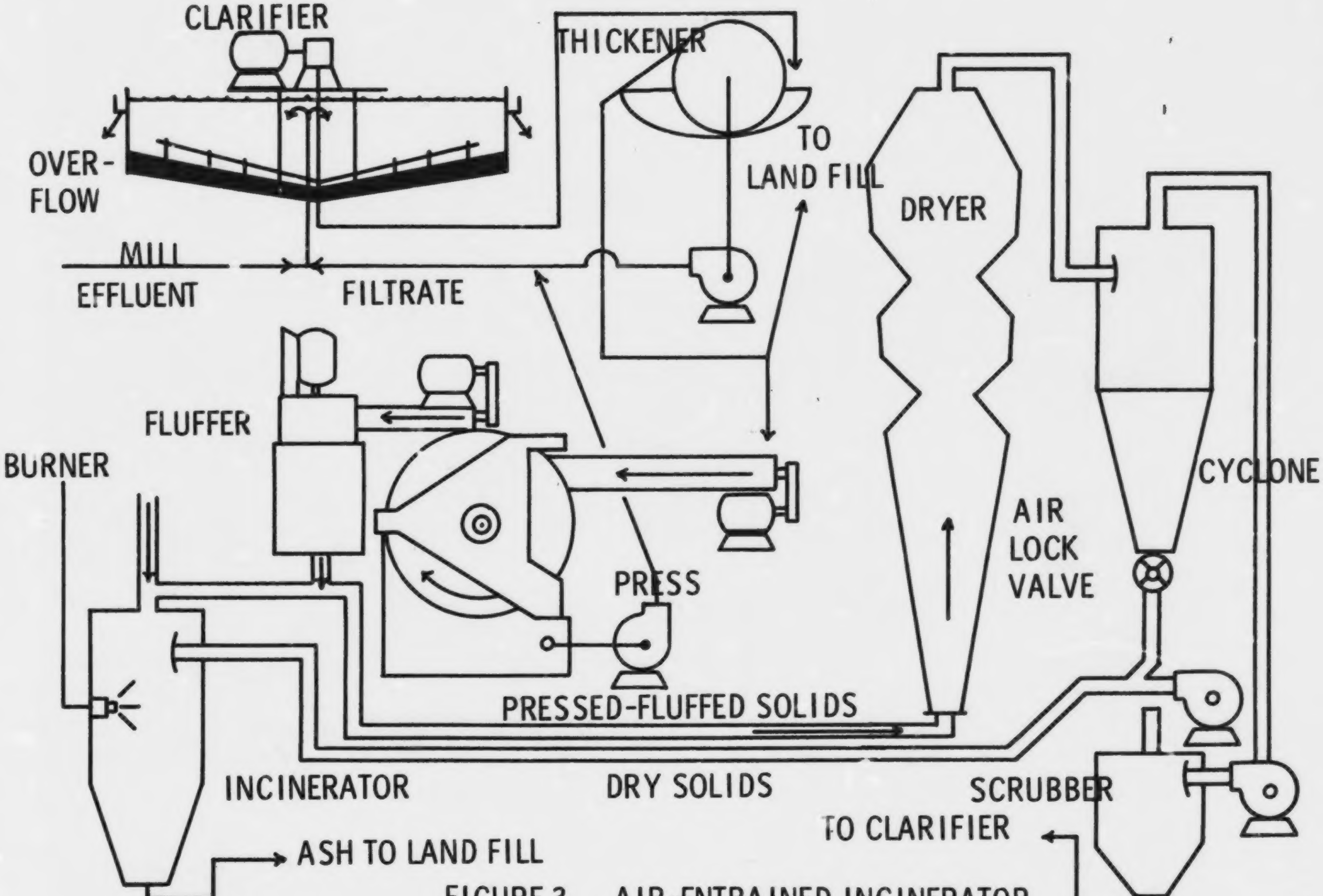


FIGURE 2. AIR ENTRAINED INCINERATOR--SIDE VIEW.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FLUFFER
BURNER
PRESS
PRESSED-FLUFFED SOLIDS
INCINERATOR
DRY SOLIDS
SCRUBBER
TO CLARIFIER
ASH TO LAND FILL

FIGURE 3. AIR-ENTRAINED INCINERATOR

is low. Secondary air enters the incinerator tangentially above the gas burner. Ash drops out of the bottom onto a water cooled metal chain drag conveyor. Water is also sprayed onto the ash to cool it prior to its transfer to a rubber conveyor belt, going to land fill. By a transfer chute, sludge from the coil filter can go to land fill on this belt when the incinerator is down.

For many of the disposal methods investigated, large amounts of pressed and fluffed sludge were taken from the system. This could be done by not running the fans, dryer, and incinerator. A flange is removed from under the fluffer, and sludge falls onto a portable conveyor which can be elevated to take the sludge up into a dump truck for transport to the site of use. Most of the sludge for the experimental farm and for the burning trial in the Camas hog fuel furnace was obtained this way.

A short conveyor and silage blower were used to fill chip truck trailers for the hog fuel trial at our Port Townsend kraft mill located in the State of Washington. Figure 4 shows a flow sheet which would be used by mills for disposing of sludge by burning in hog fuel furnaces.

Smaller amounts of coil filter sludge at 18-22% solids were obtained for some uses. The first farm application was collected by using a front end loader and dump truck to remove material from the land fill area. This method was not used after start-up of the incinerator in 1969. Only small amounts of dried sludge at 70-85% solids can be obtained during operation of the incinerator by drawing them off with a vacuum source from a port in the material conveying duct to the incinerator. It is possible to operate the system as a dryer by burning only gas, and removing dried sludge from below the rotary air lock valve. This system is shown in Figure 5.

In disposing of paper mill primary treatment plant sludge by incineration, the objectives were to obtain the operating costs, note any operational problems, and to determine whether the process would meet emission standards set for air, solid waste, and water effluent. All operating data on the plant were logged, and the air-entrained incineration system was given a separate account number so that all costs could be tabulated. The basic data given in this report were accumulated from monthly summary sheets prepared

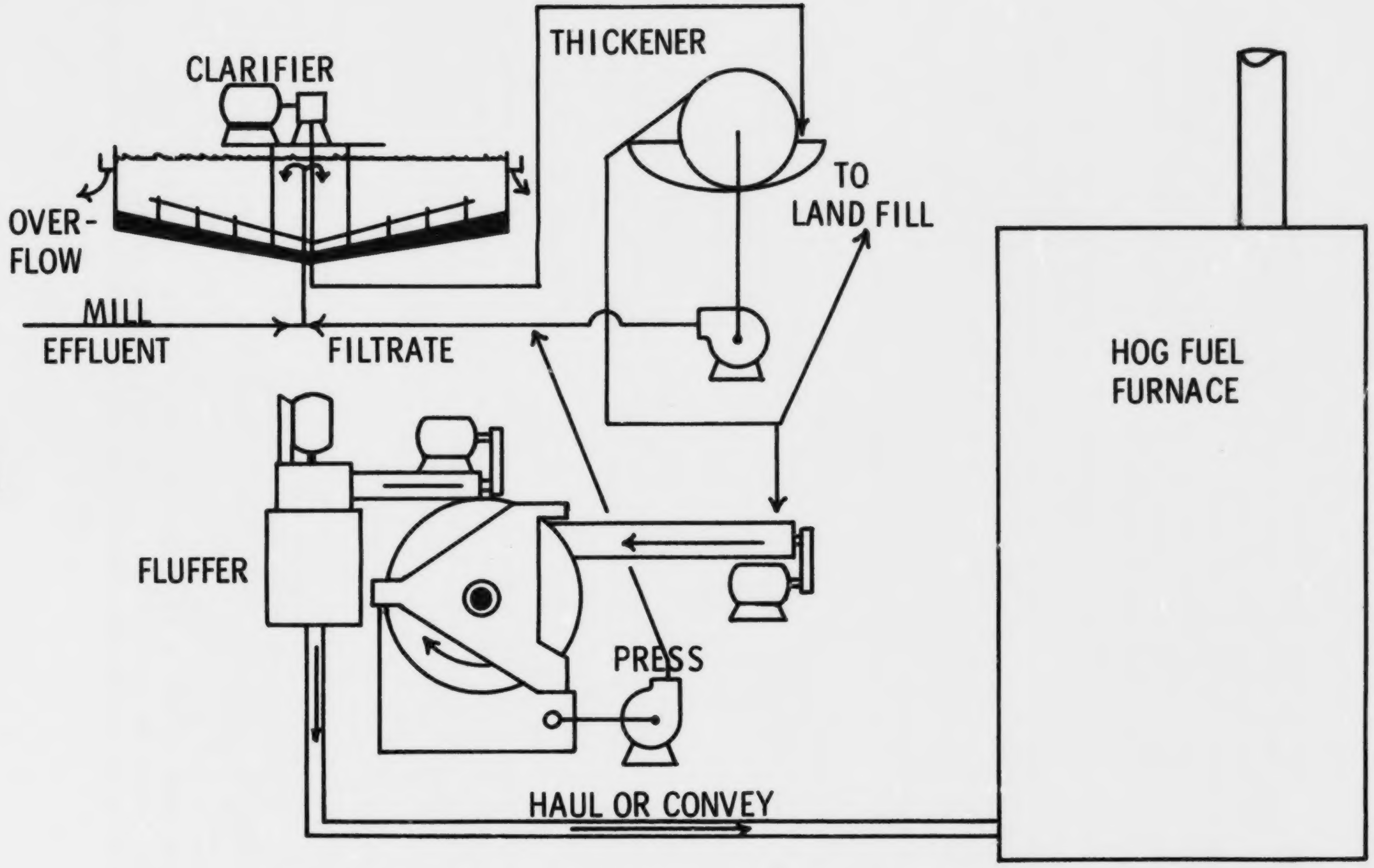
CLARIFIER
THICKENER
OVER-
FLOW
TO
LAND FILL
MILL
EFFLUENT
FILTRATE
HOG FUEL
FURNACE
FLUFFER
PRESS
HAUL OR CONVEY

FIGURE 4. PRESSED SLUDGE--BURN WITH HOG FUEL

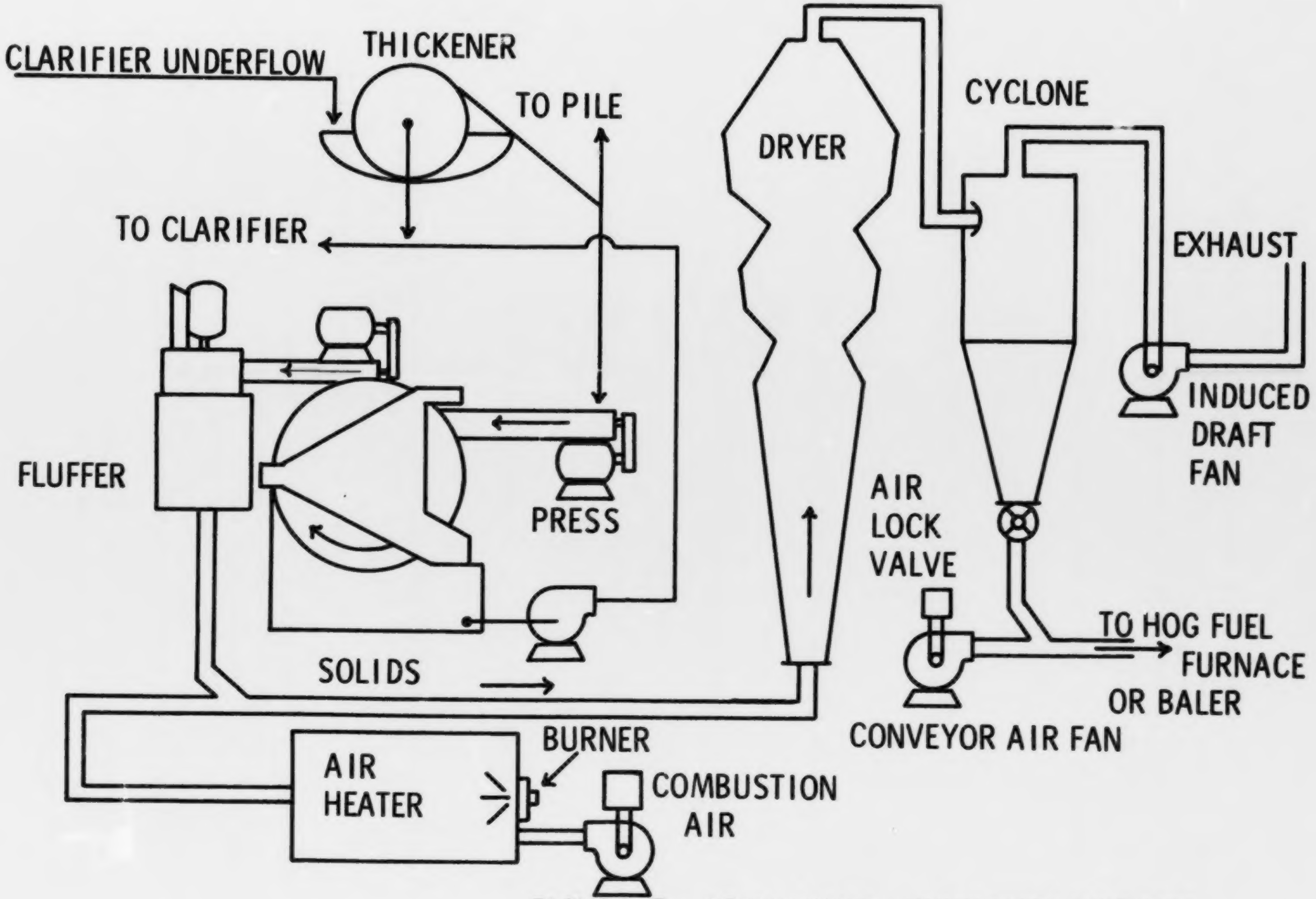
CLARIFIER UNDERFLOW
THICKENER
TO PILE
TO CLARIFIER
FLUFFER
PRESS
SOLIDS
AIR HEATER
BURNER
COMBUSTION AIR
DRYER
CYCLONE
EXHAUST
INDUCED DRAFT FAN
AIR LOCK VALVE
TO HOG FUEL FURNACE OR BALER
CONVEYOR AIR FAN

FIGURE 5. DRY SLUDGE--BURN WITH HOG FUEL

by both the operating and accounting departments of the Camas Mill. All special testing and projects were undertaken by personnel assigned from the Central Research and Environmental Services Divisions of Crown Zellerbach Corporation.

A summary of 3 years operation is given in Table 4.

TABLE 4

PRIMARY TREATMENT PLANT OPERATING DATA

Year	1970	1971	1972
Total Tons Sludge to Plant	19,561	15,307	20,284
Total Tons Sludge Incinerated	16,041	14,249	17,067
Total Tons Sludge to Land Fill	3,520	1,058	3,217
% of Sludge Incinerated	82.0	93.1	84.2
Total Gas Usage, M cu ft	15,100	10,686	12,278
Gas Usage, Btu/lb Sludge	497	396	380
Power Usage, kw-hr/lb Sludge	0.0545	0.0492	0.0537

The data show that the air-entrained incinerator operated over 80% of the time, and that as a back-up there should be the option of diverting sludge to land fill. For short periods of downtime, sludge can be accumulated in the clarifier; and this can be monitored by noting the amperage on the clarifier rake arm motor drive. For each pound of sludge burned, approximately 400 Btu must be supplied from auxiliary fuel. From an installation of over 400 horsepower, usage is about 0.05 kw-hr/lb of sludge burned. Capacity of the plant appears to be slightly less than 50 tons/day of solids.

The operating costs for disposal of sludge were taken from mill accounts for the years 1970-1972. These are given in Table 5.

TABLE 5

OPERATING COSTS FOR INCINERATING PRIMARY TREATMENT PLANT SLUDGE

Year	1970	1971	1972
Tons Sludge Incinerated	16,041	14,249	17,067
Direct Costs, $			
1. Operating Labor-- Ind. Fringe Benefit	23,146	22,246	27,272
2. Repair Labor-- Ind. Fringe Benefit	7,610	20,488	20,490
3. Repair Materials	46,901	30,536	23,852
4. Misc. Supplies, Expense	--	89	389
5. Electrical Power	6,120	4,915	6,412
6. Natural Gas	10,005	10,140	9,489
Totals, $	93,782	88,415	87,904
Indirect Cost (20% Labor), $	6,151	8,547	9,552
Fixed Costs, $			
1. Depreciation, 10% Cap. Cost	35,000	35,000	35,000
2. Taxes and Insurance, 1.85% Cap. Cost	6,470	6,470	6,470
Totals, $	41,470	41,470	41,470
Return on Investment, 8%, $	28,000	28,000	28,000
Total Cost, $	169,413	166,431	166,926
Incineration Cost/Ton, $	10.56	11.68	9.78
Filtration Cost/Ton, $	2.76	2.92	3.06
Total Disposal Cost/Ton, $	13.32	14.60	12.84

The entire primary treatment plant and sludge disposal by incineration system can be operated by one man per shift. Labor cost is split 50-50 between each, and only the incineration half is shown in Table 5. All controls are centrally located, and the major pieces of equipment are adequately instrumented. The operator is responsible for sampling various flows for consistencies. The whole operation is supervised at the Camas Mill by the sulfite pulp mill.

The major operating cost is maintenance, attributable to wear caused by grit and ash in the sludge. Table 6 shows a breakdown in hours of maintenance time on specific pieces of equipment for the years 1971 and 1972.

TABLE 6

MAINTENANCE DOWNTIME--EQUIPMENT EVALUATION

Year	1971		1972	
	Hours	% of Time	Hours	% of Time
Conveyor and V-Press	187	11.26	218.5	12.44
Fluffer	74.5	4.48	87.5	5.04
Cyclone, Dryer, Rotary Air-Lock Valve	136	8.18	257	14.64
Incinerator	418.5	25.19	275	15.67
Ash Conveyor	56.5	3.40	36	2.05
Scrubber and Its Fan	131.5	7.92	89	5.07
Other Fans	26.0	1.56	20	1.14
Instruments--Controls	173.5	10.43	77.5	4.42
Misc. Downtime, General Maintenance	458.5	27.58	694	39.53
Totals	1662.0	100.00	1754.5	100.00

The V-press required 11-12% of the total down-time. The conveyor chute to the press caused some early problems, mainly due to plug-ups. These have been minimized by redesign of the chute and better control on the V-press inlet mechanism. Filter sludge now is automatically transferred to the conveyor belt to land fill when the chute plugs, and this relieves the operator of a nasty clean-up problem when plugging occurs. Press screens show wear and must be changed several times a year. There has been some maintenance on the eddy current press speed control.

An important factor in drying and burning sludge is to have the material from the press well fluffed or opened up. This is done by dropping pressed sludge through a fluffer, or hammer mill. In 1970, fluffer hammers were replaced 44 times, and fluffer screens 12 times. This was a major maintenance item. Use of hardened alloy hammer tips and a reduction in ash content of the sludge decreased hammer replacements to about once a month during 1971 and 1972. Screen replacements were down to one or two a year.

High ash content of the sludge has contributed to erosion of high velocity areas of the dryer, cyclone, and ducts to and from them. Flatbacks have been installed at elbows and places of wear. Wiper blades on the rotary air-lock valve require frequent replacement.

Downtime on the incinerator has been for slag removal, modifications to the ash discharge, and replacement of refractory. The latter wears out by erosion in areas of high velocity.

The other major item of maintenance has been the wet fan dynamic scrubber and the cyclone separator, following the fan. The original equipment was made of mild steel, and the fan housing and separator body were coated with asphaltum. Thickness gage tests showed wear in high velocity areas. Corrosion tests also showed that mild steel would corrode in this environment, but that 304 stainless steel would be satisfactory. All these items have now been replaced with stainless steel, and maintenance costs have been reduced.

Generally, an air-entrained incineration system can be expected to have high maintenance costs due to high temperature-high velocity gas and solids flows, and due to the abrasive property of high ash sludge.

The current regulation on particulate emissions for incinerators is 0.1 grain/standard dry cu ft gas at 70° F., corrected to 12% CO_2. Due to velocity problems in the scrubber outlet stack, early tests had to be made by measuring particulate to the scrubber and particulate in the scrubber water. The difference was assumed to be emitted to atmosphere. Results, shown in Table 7, indicated that the system could meet the regulation.

More recent tests were conducted after the scrubber stack was modified to give a better velocity profile. The results in Table 8 are measurements being emitted to the atmosphere. Both tests gave values below 0.1 grain/standard dry cu ft, at 70° F., corrected to 12% CO_2.

To satisfy both the operating division and the pollution control authorities, one has to know both the flows and amounts of solids in the streams going to and coming from the various units in the system. Many of the streams carry solids, and flows can be large. Selection of methods for measurements should be both practical and reliable. Consistency, or solids content, is normally taken on all flows. Large liquid flows are usually measured with weirs. Smaller streams, such as the filter filtrate and press pressate could be measured with weirs, or possibly orifices, if the flow is pumped. Attempts have been made to measure slurry flows by counting the strokes and knowing the displacement of positive displacement pumps. This is not always reliable because solids can lodge under check valve seats.

Dewatered solids are usually transferred from one piece of equipment to another by belt conveyors. This offers the possibility of measuring flows by the use of belt weighing devices. Solids flow can be measured on a filter drum by taking a measured area of the filter cake, and relating the dry solids in it to the total filter mat. This is determined by knowing the filter drum speed, diameter, and width. Uniform cake thickness is assumed.

The primary treatment plant operator takes consistencies on the following streams:

Clarifier Influent
Clarifier Effluent
Sludge to Filter
Filter Cake
Filtrate
Press Cake
Pressate

TABLE 7

PARTICULATE EFFICIENCY TESTS ON INCINERATOR SCRUBBER

Test No.	Scrubber Flow, ACFM	Temp., ^{o}F. Wet Bulb	Dry Bulb	Particulate, lb/hr In	Out*	Emission, Grains/Std Dry Cu Ft**	Scrubber Effic., %
1	22,530	237	142	13.4	0	0	100
2	22,530	237	142	16.0	0.6	0.0176	96
3	22,230	275	140	19.63	3.26	0.107	83.4

*Measured in scrubber water discharge and subtracted from inlet particulate.

**Corrected to 14.7 psia, 12% CO_2.

TABLE 8

PARTICULATE EMISSIONS ON INCINERATOR SCRUBBER

Test No.	Scrubber Flow, ACFM, 70° F.	Gas Temp., °F.	Duct Veloc., fps	% Carbon Dioxide	% Water Vapor	Particulate, Gr/Std Dry Cu Ft, 70° F.*
1	32,650	117	47.0	2.5	7.3	0.051
2	33,300	117	48.3	2.0	6.3	0.066

*Corrected to 14.7 psia, 12% CO_2.

Clarifier effluent is measured by a Parshall flume, and this is assumed to be practically the same as the influent. A flow pipe and V-notch weir were built to measure pressate flow, and this can be measured. The operator also measures sludge flow by taking 4" by 4" filter cake samples off the filter drum. From all these data, all flows can be determined by using the MATERIAL BALANCE FORMULA, given in Figure 1A in the Appendix.

For a period of 5 days, extensive samplings and data were taken to check the reliability of testing procedures. The regular test data taken by the primary treatment plant operator were supplemented by numerous tests and readings taken around the clock by project personnel. Measured quantities are given in Table 9.

From these data, the calculated quantities of Table 10 were obtained.

Using the two manually measured or observed flows of pressate and filter cake pads, the O.D. tons of solids going to the incinerator (as press cake) were calculated. The filter cake daily tonnages were consistently higher. Differences between influent, effluent, and press cake solids are assumed to be either positive or negative accumulations in the clarifier. There are no definite conclusions to be drawn about the accuracy of either measurement for material balance data. The results point out, however, that some flow within the system should be continually measured and accumulated by an integrating recorder to obtain meaningful data on the amount of solids going through the disposal plant.

TABLE 9

MATERIAL BALANCE DATA--MEASURED QUANTITIES

Day Ending	8/17/70	8/18/70	8/19/70	8/20/70	8/21/70
Consistencies, %					
Clarifier Influent	0.033	0.031	0.018	0.021	0.0295
Clarifier Effluent	0.004	0.004	--	--	0.0002
Sludge to Filter	2.67	2.525	2.425	2.356	2.548
Filter Cake	16.58	16.94	17.00	15.86	17.28
Filtrate	0.037	0.045	0.046	0.039	0.031
Press Cake	40.90	41.68	39.80	37.71	38.00
Pressate	0.342	0.364	0.435	0.410	0.479
Ash Content, O.D. Solids Basis, %					
Filter Cake	16.01	21.87	18.18	17.68	16.26
Press Cake	16.52	22.43	19.65	17.19	16.49
Incinerator Ash	92.8	61.81	91.09	92.92	91.14
Gal/Day to Clarifier x 1000	55,899	55,416	57,758	56,773	57,800
Pressate Flow, gpm*	35	29.1	33.8	31.5	31.45
Hours Incin. Operation	24	24	18	24	22.5
Gas Usage, cu ft/day	16,700	13,000	8,600	13,400	18,600

*Calculated from weir readings on pressate flow.

TABLE 10

MATERIAL BALANCE DATA--CALCULATED QUANTITIES

Day Ending	8/17/70	8/18/70	8/19/70	8/20/70	8/21/70
Solids in Influent, tons	77.0	71.6	43.7	49.7	71.2
O.D. Tons Press Cake*	57.5	48.9	44.0	50.5	54.5
O.D. Tons Press Cake**	64.7	66.7	49.9	63.5	60.7
Solids in Effluent, Tons	7.1	6.9	10.8	7.1	4.8
Accum. in Clarifier, Tons*	12.4	15.8	-11.1	-7.9	11.9
Accum. in Clarifier, Tons**	5.2	-2.0	-17.0	-20.9	5.7
% Losses in Effluent	9.24	9.68	24.8	14.3	6.77
Lb Loss/1000 Gal.	0.33	0.35	1.55	0.50	0.23
Therms Gas Used/Ton Sludge	3.07	2.81	2.06	2.81	3.60

*Calculated from weir flow readings, pressate cons.

**Calculated from 4" x 4" pad taken from coil filter, filter speed, filter area, filter cake cons. (mill data).

SECTION VI

INCINERATION--HOG FUEL BOILERS

Pressed and fluffed sludge was taken from the Camas Mill primary treatment plant to the Port Townsend Mill for a trial of burning with hog fuel in a steam generating dutch oven furnace. Sludge was transferred with a silage blower into chip truck trailers, transported to the mill and dumped onto the purchased chips conveying system. A transfer conveyor moved sludge from the chip area to an empty hopper in the steam plant. Fuel mixes for burning were made by taking relative amounts out of the sludge and hog fuel hoppers with a scoop, operated from an overhead monorail track. The actual ratios of fuel components were determined by manual separation of sludge and hog fuel from composite samples taken from the furnace feed chutes. Fuel usage, steam production, CO_2 in the flue gas, and ash pit pressure were monitored during the run.

For the hog fuel burning trial at Camas, pressed and fluffed sludge was taken from the incineration plant by the method of portable conveyor and dump truck. An area adjacent to the hog fuel pile was used for stock piling. Hog fuel is pushed into a trough, which is kept filled with fuel. Drag chains in the bottom of the trough move the material against a dam, and this gives a continuous uniform volume flow of fuel. At the point where the material is transferred to conveyor belts, sludge was manually shoveled onto the belt at a rate estimated to give the desired proportion of sludge. This flow was then taken to the furnace directly. The furnace was loaded for 10 minutes out of each hour, and a composite sample of each load was taken for moisture, ash, and heating value tests. The amount of sludge in each mix was calculated by knowing the ash content of the sludge, the hog fuel, and the fuel mix. An example of the method is given as follows:

Sludge = 19.68% Ash
Hog Fuel = 2.74% Ash
Fuel Mix = 3.64% Ash
Let a = Fraction Hog Fuel
Let b = Fraction Sludge
$a + b = 1 \quad (1)$
$0.0274\,a + 0.1968\,b = 0.0364 \quad (2)$

Substituting (1-a) for b, and solving the second equation gives a = 0.947, and then b = 0.053, or the fuel is 94.7% hog fuel and 5.3% sludge.

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The objectives of the sludge-hog fuel burning trials were the following:

a. Determine the ratio of sludge to hog fuel which can be burned in a steam generating boiler.

b. Note the effects on operation and steam production.

c. Determine the cost of this method of disposal.

d. Note effects on smoke emissions to the atmosphere.

The trial at the Port Townsend Mill was primarily to test this method of disposal in order to allow for future planning. Hog fuel and sludge properties for this trial are given in Table 11.

TABLE 11

HOG FUEL AND SLUDGE PROPERTIES--
PORT TOWNSEND TRIAL

	Sludge	Hog Fuel
O.D. Solids, %	37.25	56.75
Ash, O.D. Basis, %	19.68	2.14
Aver. Wet Density, lb/cu ft	26.7	24.3
Heating Value, O.D. Basis, Btu/lb	6130	9250

These fuel properties are the normally expected values except that sludge solids content is slightly lower than average. It is interesting to note that the two materials have similar bulk densities. This enabled the operator to make fuel mixes fairly accurately by volumetric measurement. Furnace operating data are shown in Table 12. The average conditions in the boiler were set during the first 4 hours of the run. Thermal efficiency of the boiler with hog fuel has been assumed to be 58.2%. When sludge and hog fuel were added, the early effects were an increase in ash pit pressure on the forced air fan and a lowering of the CO_2

TABLE 12

FURNACE OPERATING DATA--CAMAS SLUDGE AND PORT TOWNSEND HOG FUEL BURNING TRIAL AT PORT TOWNSEND

Period of Run, hr.	4	17	12	4
Tons Dry Fuel Mix/Hr	5.25	3.12	2.50	2.75
Sludge in Dry Fuel, %	0	12.5	22.3	0
Ash in Dry Fuel, %	2.14	5.32	6.04	2.14
Tons Dry Sludge Used/Hr	0	0.390	0.557	0
Dry Fuel Therms Input/Hr	972	553	429	508
Steam Prod., M lb/hr*	49.6	26.6	18.2	19.8
Thermal Effic. of Boiler, %**	58.2	58.0	53.7	47.2
Tons Ash/Hr	0.1124	0.1660	0.1511	0.0588
CO_2 in Flue Gas, %	8-12	6-8	6-8	6-8
Ash Pit Pres., " H_2O	0.2	1.15	1.20	1.20
Reduction in Thermal Effic., %	--	0.3	7.7	18.8
Reduction in Dry Fuel Heat Value, %	--	4.3	7.6	--

*Lb Steam (1000 Btu/lb), corrected for feed water temp., etc.

**Assumes evaporation of moisture in fuel and 1000 Btu/lb steam produced.

content of the flue gas. This indicates that more air is needed to burn the fuel. Upon continuation of the run at the high sludge fuel content of 22.3%, the reduction in thermal efficiency becomes proportional to the lower heat value of sludge. The final portion of the run without sludge shows that the accumulation of ash from the sludge has given the furnace a residual of lowered thermal efficiency and reduction in steam production.

In order to extend the information gained from the trial at Port Townsend, a 4 day run of burning sludge-hog fuel mixes was planned for a hog fuel boiler at Camas. This provided a better opportunity to note effects on furnace operation, steam production, and emissions of smoke to the atmosphere. Sludge and hog fuel properties for this trial are given in Table 13.

The furnace operating data for the Camas Mill sludge-hog fuel burning trial is given in Table 14.

The amounts of sludge in the fuel were calculated by the ash content method, described earlier in this section. Gas is burned in the furnace as auxiliary fuel, and its heat contribution in therms (100,000 Btu's) is included. During daylight hours of the trial a trained observer noted Ringlemann No. on the boiler stack emission. The only value over 1.0 resulted from an overloading of the furnace. As previously mentioned, the boiler was operated by filling with fuel every 10 minutes out of each hour.

Results show that the reduction in boiler thermal efficiency is related to the higher ash content and lower calorific fuel value of sludge, compared to hog fuel. The latter on an ash-free basis would be about 8100 Btu/lb for sludge and about 9550 Btu/lb for hog fuel.

As the tons of ash accumulate in the furnace, the thermal efficiency of the furnace also drops, and this is illustrated to be true whether sludge has been burned or not (the data taken on 11/3). The conclusion from both the Camas and Port Townsend trials is that if a high-ash sludge (approx. 20%) is to be burned in a hog fuel boiler, it should be no more than 5% of the fuel mix. Even at this low level, based on ash accumulation and a 7 day furnace cleaning cycle without sludge, the furnace would have to be cleaned every 5 days.

TABLE 13

HOG FUEL AND SLUDGE PROPERTIES--CAMAS TRIAL

I. Sludge Sample, Collected 10/12/70.

O.D. Solids, % = 38.3
Ash, O.D. Basis, % = 19.68

II. Heating Values on Sludge and Fuel Mixes, Btu/lb, O.D. basis.

Sludge collected on 10/12/70	6,500
Hog Fuel Mix (5.3% sludge), day ending 10/15/70	9,118
Hog Fuel Mix (13.3% sludge), day ending 10/16/70	8,835
Hog Fuel Mix (17.1% sludge), day ending 10/17/70	8,831
Hog Fuel Mix (8.0% sludge), day ending 10/18/70	9,030

III. Hog Fuel Properties

Day Ending	10/15	10/16	10/17	10/18
O.D. Solids, %	48.5	47.0	47.5	48.9
Ash, O.D. Basis, %	2.74	3.04	2.02	2.39
Heating Value, Btu/lb, O.D. Basis*	9,270	9,200	9,320	9,250

*Calculated from hog fuel mix data.

TABLE 14

FURNACE OPERATING DATA--CAMAS SLUDGE AND HOG FUEL BURNING TRIAL AT CAMAS

Day Ending	10/15	10/16	10/17	10/18	11/3*
Tons Dry Fuel Mix/Day	35.4	39.4	41.7	36.4	18.5
Sludge in Dry Fuel, %	5.3	13.3	17.1	8.0	0
Ash in Dry Fuel, %	3.64	5.25	5.04	3.77	?
Tons Dry Sludge Used/Day	1.88	5.24	7.12	2.91	0
Therms Gas Used/Day	6,270	6,410	5,560	5,575	10,950
Therm Equiv.-Dry Fuel/Day	6,450	6,970	7,370	6,575	3,425
Steam Prod., M lb/day	855	866	833	782	931
Thermal Effic. of Boiler, %**	67.0	65.3	65.4	64.8	62.6
Tons Ash/Day	1.29	2.07	2.10	1.37	?
Maximum Ringlemann No.	1.2***	0.7	0.7	0	?
Reduction in Dry Fuel Heat Value, %	1.6	4.1	4.9	2.2	--
Reduction in Boiler Thermal Effic., %****	1.6	3.9	3.8	4.7	--

*Day before furnace cleaning.

**Assumes evaporation of moisture in fuel and 940 Btu/lb steam produced (feed water temp. 258° F.).

***High Ringlemann No. due to overloading the furnace.

****Assumes thermal effic. with no sludge is 68.1%.

A cost estimate has been made for disposal of sludge in a hog fuel boiler. The bases for the estimate are given as follows:

1972 Operating Costs -- Assume 17,076 tons to boiler.
Plant cost for pressing sludge = $120,000.
Sludge contains 60% water.
Dry fuel heating value = 6315 Btu/lb.
Steam cost $0.55/1000 lb.
Hog fuel contains 52% water.
Dry hog fuel heating value = 9250 Btu/lb.
Maintenance cost 30% of total incineration cost,
same for miscellaneous supplies, expenses.
Power cost 40% of total incineration cost.

Calculation

Difference in cost between burning one dry ton sludge versus one dry ton hog fuel:

Loss in Btu value = (2000)(9250 - 6315) = 5870 M Btu
Added Water Evap. = (2000)(1050)(0.42) = 880 M Btu

Total Difference = 6750 M Btu

Loss/ton sludge, assuming steam @ 940 Btu/lb:

$$(0.55)\left(\frac{6750}{940}\right) = \$3.95\text{/ton sludge}$$

The cost estimate for burning pressed sludge in a hog fuel boiler assumes that the material can be furnished to the boiler at no handling charge. This means that dewatering and pressing facilities are located adjacent to the hog fuel storage area, and that the two fuels can be blended. Table 15 shows that there would be a savings of about $1.50 by disposing of sludge in a hog fuel boiler over incineration.

TABLE 15

COST OF PRESSING, BURNING SLUDGE IN CAMAS HOG FUEL BOILER

(Based on 1972 Operating Costs)

Direct Cost--Pressing Sludge	$/yr.	$/Ton
1. Operating Labor - Ind. Fringe Ben.	27,272	1.596
2. Repair Labor - Ind. Fringe Ben.	6,150	0.360
3. Repair Materials	7,160	0.419
4. Misc. Supplies, Expenses	117	0.007
5. Electrical Power	2,560	0.150
Totals, $	43,259	2.532
Indirect Cost--Pressing Sludge		
1. Mill Burden (20% of labor)	6,684	0.392
Fixed Costs--Pressing Sludge		
1. Depreciation, 10% Cap. Cost	12,000	0.702
2. Taxes & Ins., 1.85% Cap. Cost	2,220	0.130
Totals, $	14,220	0.832
Return on Investment, 8%	9,600	0.562
Total Costs, Pressed Sludge, $	73,763	4.318
Primary Treatment Plant Sludge Cost, $	52,225	3.060
Loss in Fuel Value, Burning Sludge, $	67,270	3.950
Cost to Burn in Hog Fuel Boiler, $	193,258	11.328*
Cost to Incinerate Sludge, $	219,151	12.84

*The contingency of more frequent furnace cleanings is not allowed for in the estimate. Also, no cost is shown for blending sludge into the hog fuel.

SECTION VII

SLUDGE PROCESSING AND COSTS

Devices used for dewatering sludge from the underflow of a primary treatment plant are filters and centrifuges. At Camas a coil filter is used, which is a type of belt filter. Its main advantage is that it does not blind due to the continuous flexing of the layers of coils which form the belt. Sludge generally comes off the filter at 18-22% solids and is transferred by belt to land fill or to a V-press. Filtrate is returned to the clarifier. The press further dewaters the sludge to 37-40% solids, and pressate is also returned to the clarifier. The press cake is conveyed to a fluffer which breaks it up and fluffs it. This material can be flash-dried by dropping it into a stream of hot gas and carrying it through a retention vessel. It can then be separated from the gas and collected at from 50-80% solids. In dried form, the product can be densified by baling.

At each stage of dewatering sludge, in addition to a rise in solids content, there is a change in its density and a change in the solids contained in a cubic foot of the material. These figures are given in Table 16.

TABLE 16

REDUCTION OF SLUDGE VOLUME BY DEWATERING STEPS

Dewatering Device	Density, lb/cu ft	% Solids, Average	% Dry Solids/ cu ft Sludge
Filter Cake	67.5	20	10.8
Press Cake	30	38	11.4
Dryer and Baler	43.7	77	33.7

There is not much difference between the lb dry solids/cu ft of sludge in filter cake and press cake because press cake is rather bulky. Attempts to bale and densify press cake were not successful as contained water creates a continuous water phase which causes the bale to fall apart when the baling pressure is released. Pressed sludge can be bulk handled by air blower conveying, front end loaders, clamshell scoops, etc. Filter cake sludge is a fairly sloppy product which is hard to handle. For purposes of disposal, semi-drying and baling should be considered. Bales have been made successfully from sludge dried to 77-80% solids content.

For all the stages of sludge dewatering, a figure of $3.06/dry ton has been added as the cost of operating the clarifier and coil filter. This requires one operator on a half-time basis.

The degree to which sludge is dewatered and the form in which it is transported will depend on its end use. Whether it can be stockpiled or whether it can be used as received will also affect its form and determine how it is to be shipped. Pressed sludge is the most convenient form because it is the easiest to handle.

The cost of pressing sludge, developed in the previous section on disposing of sludge in a hog fuel boiler (see Table 15), assumes an installed equipment cost of $120,000. This includes a transfer conveyor, feed chute, press, press cake conveyor, and fluffer. Power usage is estimated to be 40% of the power needed for the total disposal by air-entrained incineration, and maintenance would be 30% of that for the total plant. This brings the cost of pressing sludge to $4.32/dry ton, or with the prior dewatering cost, a total of $7.38/dry ton.

The cost for semi-drying sludge has been estimated, based on the following:

Dry one ton sludge from 40% O.D. to 77% O.D.
Drying efficiency of 70%.
Fuel cost @ $0.08/therm (100,000 Btu).
Assume maintenance 75% of incineration cost.
Production of 17,067 tons/year.
Use 1972 incineration cost data.
Capital cost of plant is $300,000.

The capital cost of the semi-drying plant is less than the incinerator because there would be no ash handling equipment.

The following calculation is made to show the cost for fuel used for drying:

Calculations

Natural Gas Cost/Ton Sludge:

Water removed/ton dry sludge = 1.2 tons
(1.2)(2000)(1050) = 2520 M Btu Required
2520 ÷ 0.70 = 3600 M Btu supplied
Cost = (3600)(0.08)(0.01) = $2.880/ton

The estimated cost of pressing and semi-drying sludge is shown in Table 17. Semi-drying would be practical only if sludge were to be made a product of commerce.

Attached to a plant for semi-drying sludge would be a baling machine. This would operate continually with the dryer, and so a full-time operator is provided. The cost of baling sludge along with the drying cost is given in Table 18.

Pressed and fluffed sludge can be conveyed or blown into trucks or barges for hauling or transport. The unloading facility would require special equipment, except for dump trucks. A ground area with cover could be provided for some storage.

Bales of semi-dried sludge could be transported by long-haul trucks or barges. Bale weights might be 1000-1400 lb gross weight, requiring fork lift trucks or hoists and slings for loading and unloading.

The costs to transport sludge on a dry ton basis are given in Table 19. These estimates are based on costs incurred in moving sludge for some of the large-scale disposal projects conducted under this EPA grant. The cost for barging was given by the Crown Zellerbach Traffic Department. It should be emphasized that all the amounts cited herein do not include selling costs, profit, or special handling charges.

TABLE 17

ESTIMATED COST OF PRESSING AND SEMI-DRYING SLUDGE

(Based on 1972 Operating Costs)

Direct Cost	$/Yr	$/Ton
1. Operating Labor--Ind. Fringe Ben.	27,272	1.596
2. Repair Labor--Ind. Fringe Ben.	15,380	0.901
3. Repair Materials	17,880	1.047
4. Misc. Supplies, Expenses	292	0.017
5. Electrical Power	6,412	0.375
6. Natural Gas	49,153	2.880
Totals, $	116,189	6.816
Indirect Cost		
1. Mill Burden (20% of Labor)	8,530	0.500
Fixed Costs		
1. Depreciation, 10% Cap. Cost	30,000	1.757
2. Taxes and Ins., 1.85% Cap. Cost	5,550	0.325
Totals, $	35,550	2.082
Return on Investment, 8%	24,000	1.404
Totals, $	184,269	10.802
Primary Treatment Plant Sludge Cost, $	52,225	3.06
Total Cost of Semi-dried Sludge, $	236,494	13.862

TABLE 18

OPERATING COSTS FOR BALING SEMI-DRIED SLUDGE

Basis: 1972 production of 17,067 tons, one man/shift, capital cost for baler of $68,000, installed.

Direct Costs	$/Yr	$/Ton
1. Operating Labor--Ind. Fringe Ben.	54,544	3.192
2. Repair Labor-- Ind. Fringe Ben. (4% Cap.)	2,720	0.159
3. Repair Materials (4% Cap.)	2,720	0.159
4. Electrical Power, 50 H.P.	1,000	0.059
5. Baling Materials, $1.00/ton	17,067	1.000
Totals, $	78,051	4.569
Indirect Cost		
1. Mill Burden (20% of Labor)	11,453	0.671
Fixed Costs		
1. Depreciation, 10% Cap. Cost	6,800	0.398
2. Taxes & Ins., 1.85% Cap. Cost	1,260	0.074
Totals, $	8,060	0.472
Return on Investment, 8%	5,440	0.312
Total Baling Costs, $	103,004	6.024
Cost of Semi-dried Sludge, $	236,494	13.862
Total Cost Semi-dried, Baled Sludge, $	339,498	19.886

TABLE 19

COST TO TRANSPORT SLUDGE--DRY TON BASIS

A. Long Distance Haul (500 miles round trip).

	Long-Haul Truck		Barge	
Capacity	48,000 lb Payload		46,000 cu ft	
Dewatered State of Sludge	Pressed*	Semi-Dried, Baled	Pressed*	Semi-Dried, Baled
Sludge Capacity, Dry Tons	9.1	18.5	262	850
Cost Transport/Dry Ton, $	41.20	20.25	13.18	6.48
Cost of Sludge/Dry Ton, $	7.38	19.89	7.38	19.89
Total Delivered Cost/Ton, $	48.58	40.14	20.56	26.37

B. Short Distance Haul (20 miles round trip)

	Dump Truck		Long-Haul Truck	
Capacity	10-11 cu yd		48,000 lb Payload	
Dewatered State of Sludge	Pressed	Semi-Dried, Baled	Pressed*	Semi-Dried, Baled
Sludge Capacity, Dry Tons	1.75	--	9.1	18.5
Cost Transport/Dry Ton, $	10.00	--	6.82	3.41
Cost of Sludge/Dry Ton, $	7.38	--	7.38	19.89
Total Delivered Cost/Ton, $	17.38	--	14.20	23.30

*Does not include cost of facility for unloading.

SECTION VIII

LABORATORY STUDIES

Two soils were used for the respirometer studies to determine decomposition rate of sludge material. One soil was obtained about 8 miles north of Pasco, Washington. This soil was characterized as a Rupert sand which is the predominate soil of the Pasco area and is similar to a Quincy sand. The other soil was obtained from a farm located about 3 miles northwest of Camas, Washington. A portion of this farm was leased for later field plot trials. Soil from this area is characterized as being a Hesson clay loam.

Soil moisture was determined by weighing samples before and after 24 hours at 105° C. Water holding capacity or saturation capacity of soil and sludge was calculated from the quantity of water retained by samples in Gooch crucibles after immersion in water and then allowed to drain to constant weight in a moisture-saturated atmosphere. Ash was determined by firing a weighed oven dry sample at 400° C. for 12 hours and calculating loss of volatile material. Carbon and nitrogen analysis of sludge using conventional methods was determined and calculated to have a C:N of 234:1.

An adaptation of conventional respirometer technique (2) was used to determine rate and extent of Camas sludge decomposition. Respirometers, as shown in Figure 6, consisted of pint milk bottles containing 200 grams (AD) soil mixed with varying sludge concentrations with or without supplemental nitrogen. Nitrogen additions were in the form of ammonium nitrate. Water was added to the mixture and maintained at 65% of the moisture holding capacity of soil and waste. Temperature was maintained at 30° C. in the incubated cabinet.

All treatments were triplicated and bottle location was randomized in the respirometer incubator. Sufficient air pressure was maintained to establish a minimal positive flow of air which passed through traps designed to scrub the air clean of ambient CO_2. This flow flushed CO_2 formed by microbial decomposition of sludge into test tubes containing approximately 1N caustic. CO_2 concentration was then determined by standard titration procedures

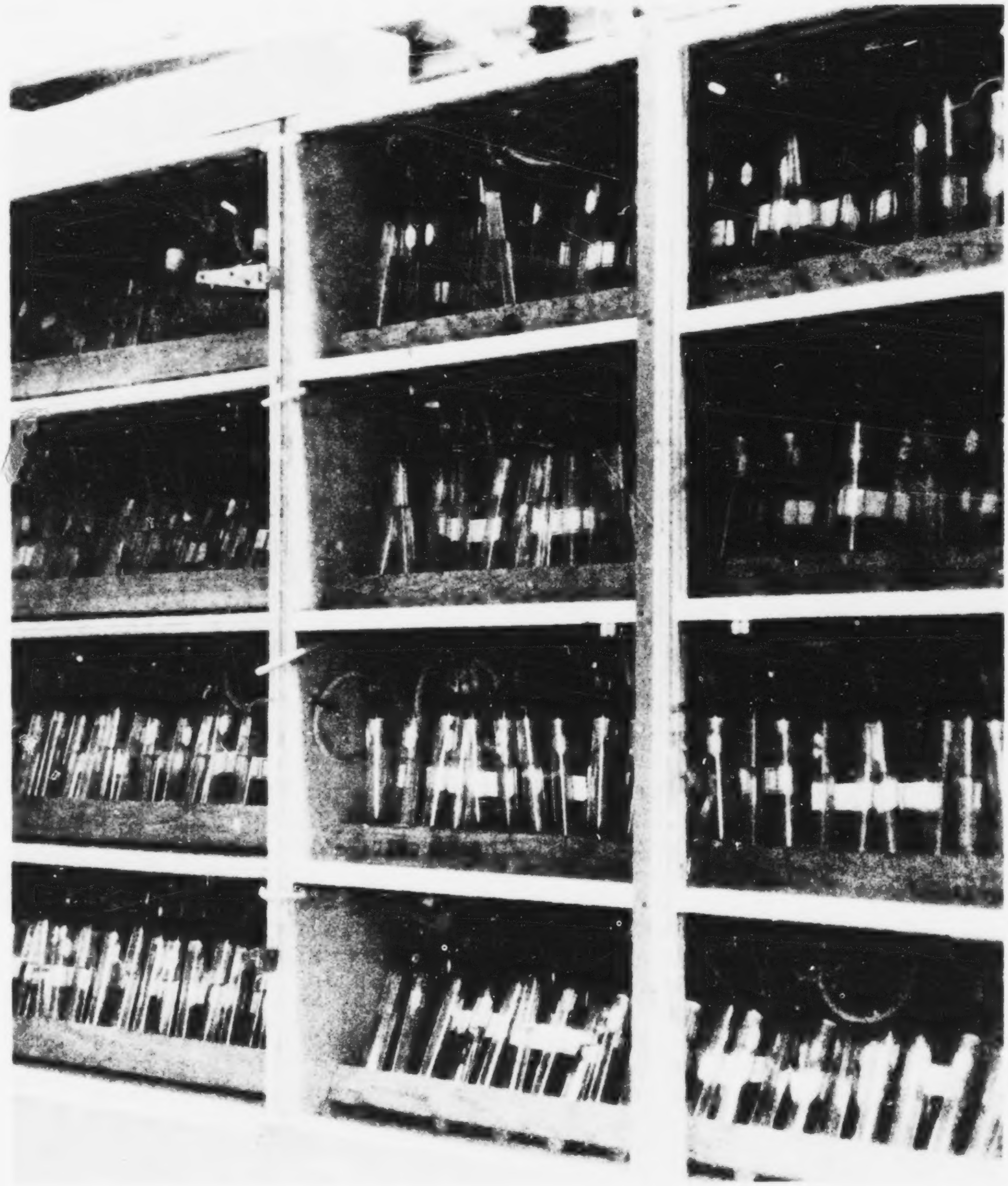


FIGURE 6. CARBON DIOXIDE RESPIROMETERS FOR DETERMINING SLUDGE DECOMPOSITION RATE.

using standardized 1N HCl. Tubes were replaced before caustic absorption capacity was exceeded with fresh caustic tubes. CO_2 evolved was recorded on a cumulative basis. The experiments were terminated after 120 days.

Because of space limitations two experiments were designed so that sludge additions ranging from 50 T/A to 600 T/A could be evaluated. In the first experiment sludge was added to the two test soils at rates of 50, 100, 150 and 200 T/A. Nitrogen was supplemented to give carbon-nitrogen ratios of 25:1 and 100:1. Controls covered sludge additions without supplemental nitrogen and nitrogen additions without sludge. Nitrogen amounts added were equivalent to those involved with sludge levels at C:N ratio of 25:1.

In the second experiment sludge was added at rates of 100, 200, 400 and 600 T/A.

Data from the two experiments, which are detailed in Tables I, II, III and IV in the Appendix, were combined and are presented in Figures 7, 8, 9, 10, and 11.

Figures 7 and 8 depict decomposition rate as tons utilized when sludge was incorporated into sandy and clay soil with supplemental nitrogen. Figure 7 shows the sludge additions as 50, 100 and 150 T/A and Figure 8 shows the higher additions of 200, 400 and 600 T/A. Ordinates differ between Figures 7 and 8. In Figure 7 the ordinates show a possible maximum of 60 tons sludge utilized. In Figure 8, which also depicts higher sludge additions, the ordinates show a possible maximum of 280 tons sludge utilization.

The graphs displayed in Figures 9 and 10 present some interesting relationships in respect to sludge levels, nitrogen requirement and soil type. For example, there was sufficiently available nitrogen present in clay soil to allow considerable breakdown of sludge when added at 50, 100, 150 and 200 T/A rates. At 400 and 600 T/A additions supplemental nitrogen was required to enhance decomposition. Conversely, with sandy soil, additional nitrogen was needed at all sludge incorporations to obtain significant sludge breakdown. It was interesting to note with the sandy soil treatments that higher nitrogen additions enhance sludge decomposition when sludge was applied at the 50, 100 and 150 T/A rates. When applied at 200, 400 and 600 T/A rates, no significant differences were noted in decomposition of sludge with the various nitrogen additions.

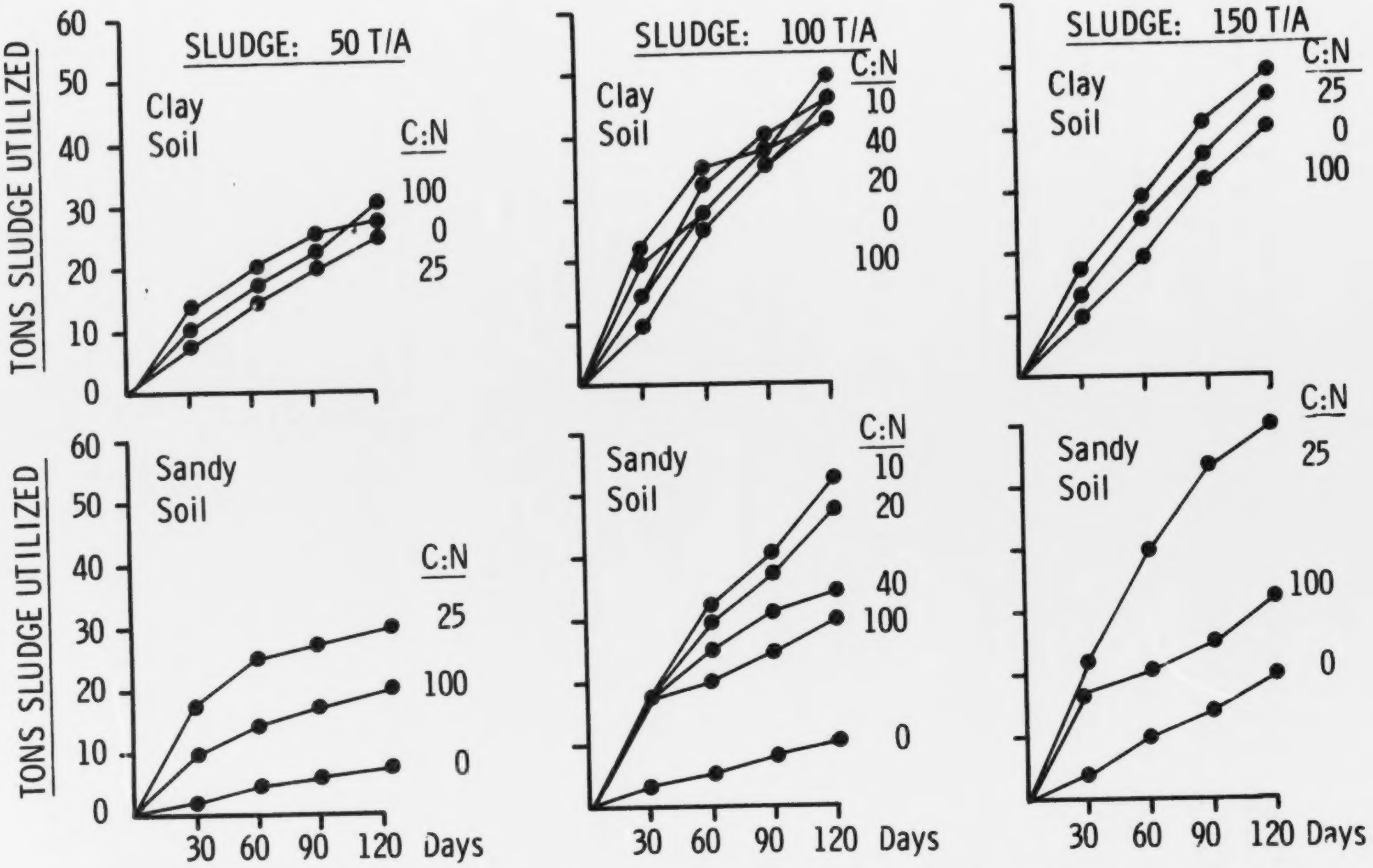


FIGURE 7. TONS SLUDGE UTILIZED AT VARIOUS LOADINGS AT DIFFERENT C:N RATIOS.

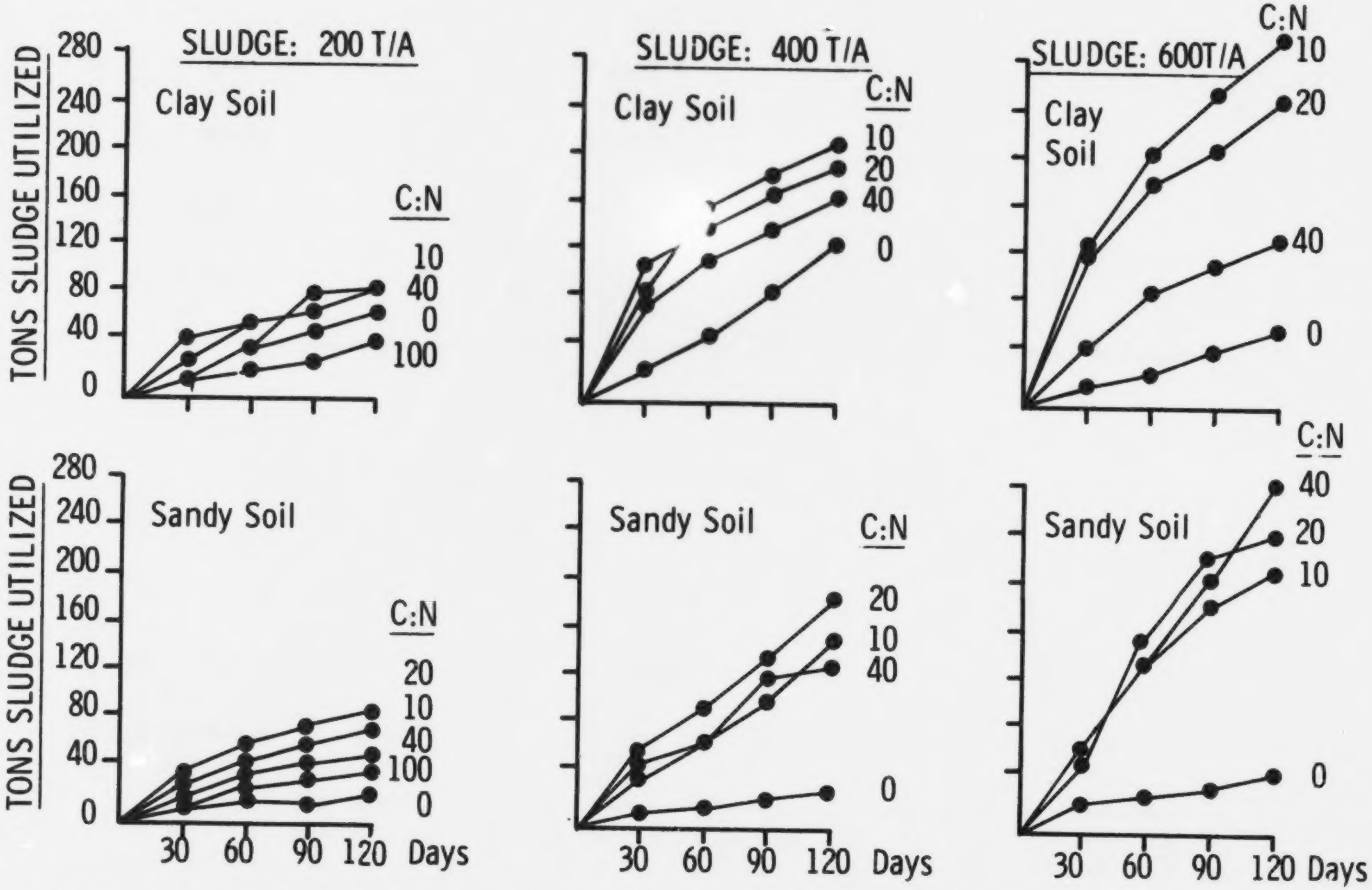


FIGURE 8. TONS SLUDGE UTILIZED AT VARIOUS LOADINGS AT DIFFERENT C:N RATIOS.

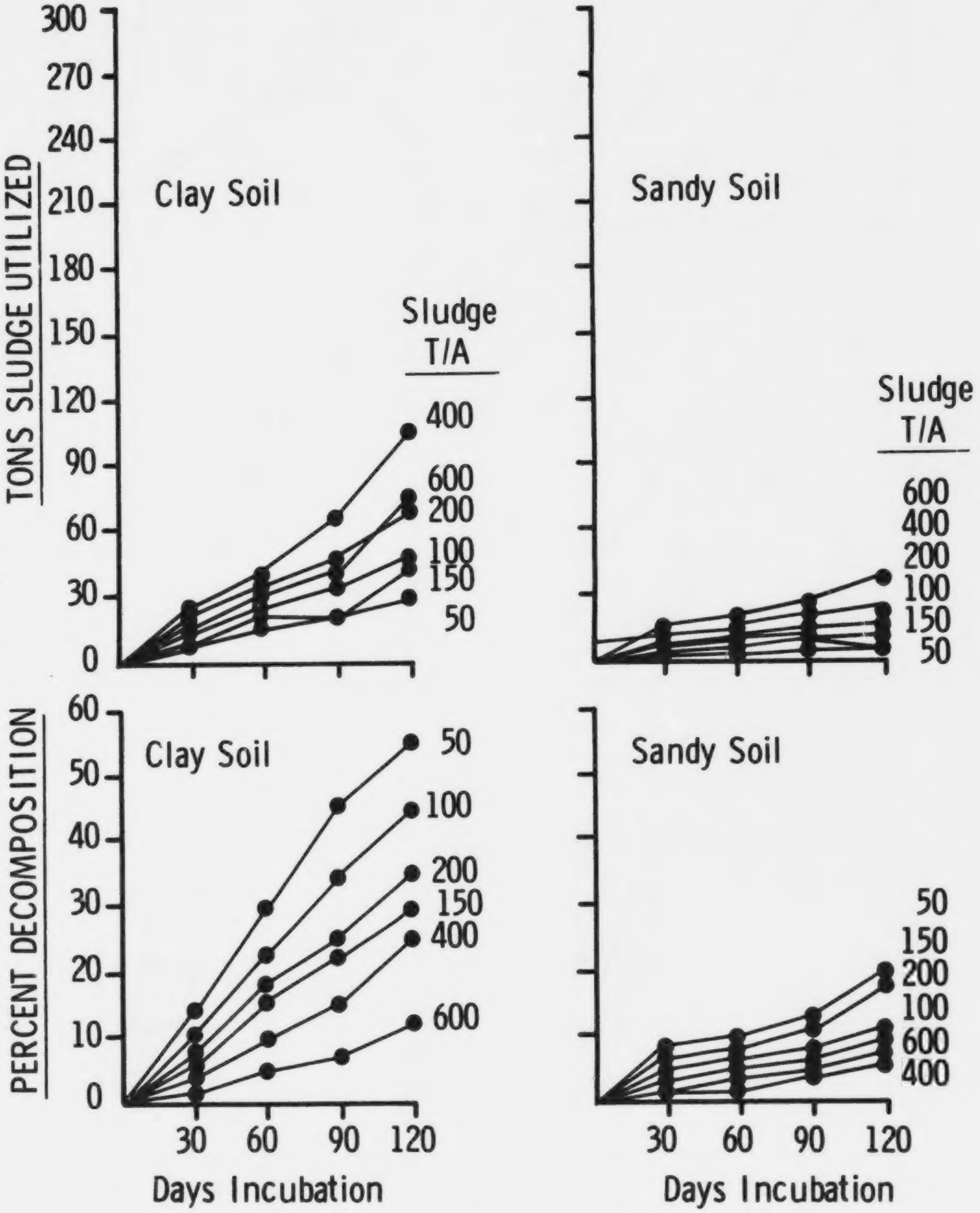


FIGURE 9. SLUDGE DECOMPOSITION--NO NITROGEN ADDED.

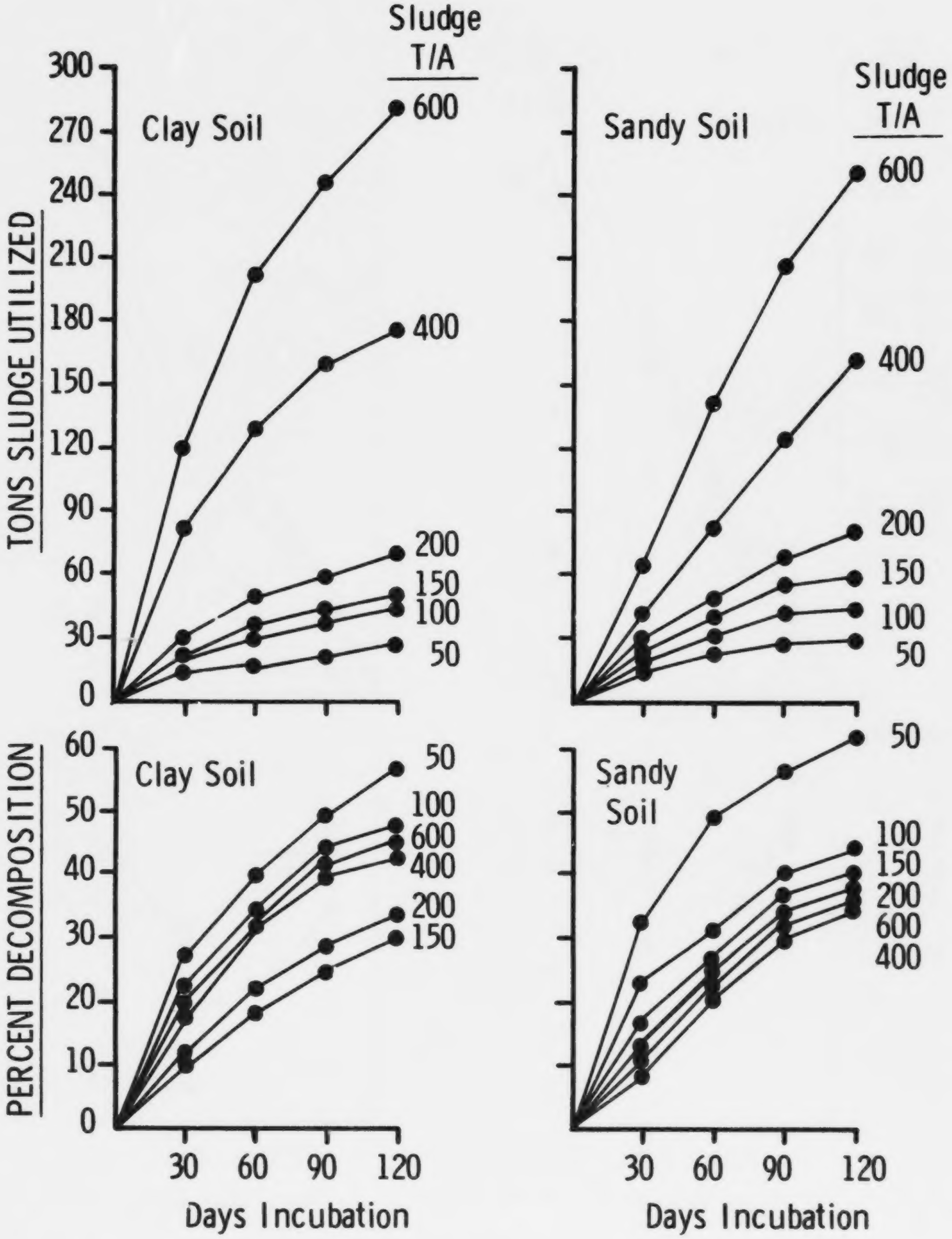


FIGURE 10. SLUDGE DECOMPOSITION -- OPTIMUM NITROGEN ADDED.

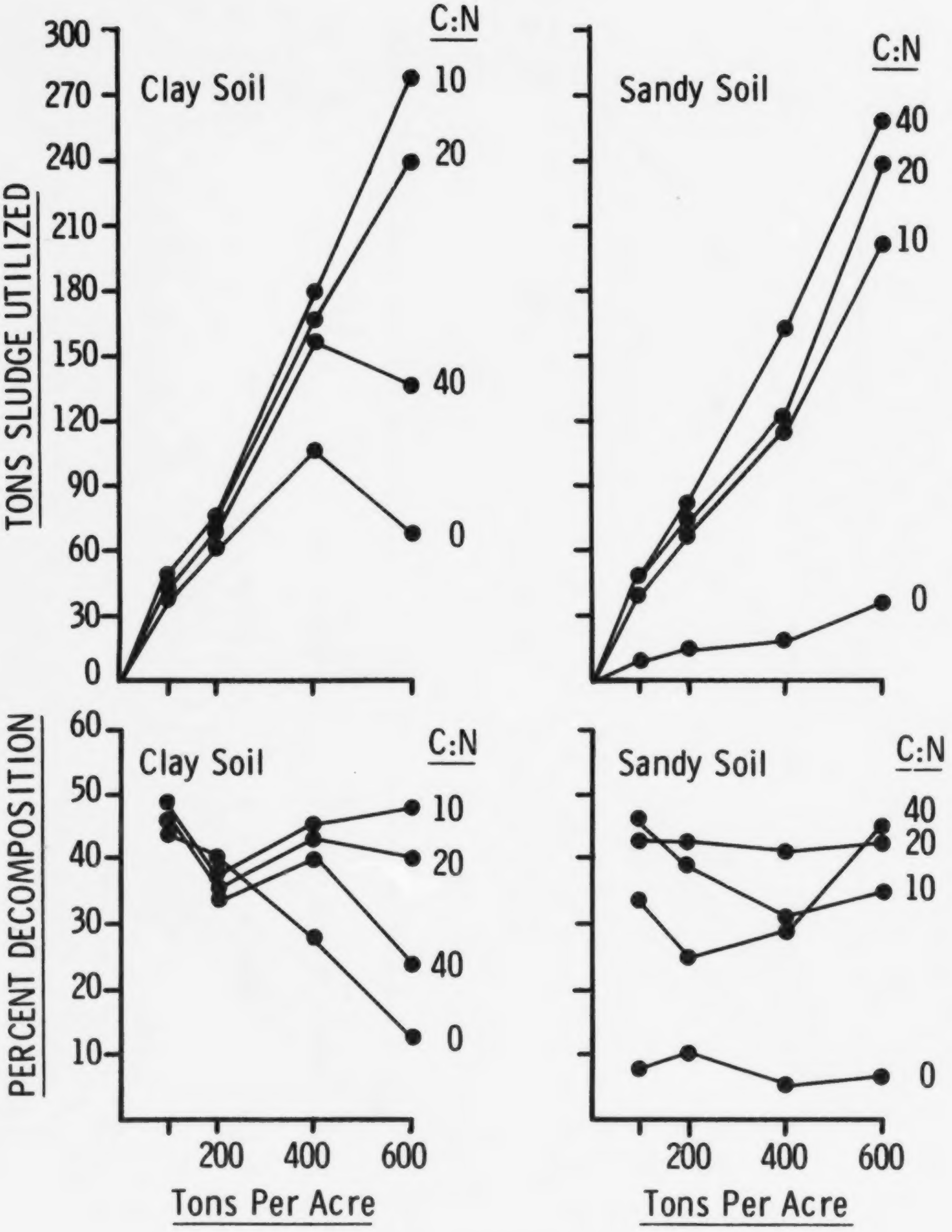


FIGURE 11 SLUDGE DECOMPOSITION IN 120 DAYS FOR SANDY AND CLAY SOIL.

Figures 9, 10 and 11 present information shown in previous figures in a different fashion. They compare decomposition rates on the ordinates as percent sludge decomposition and as tons of sludge utilized in the test soils. Curves in Figure 9 depict no nitrogen additions or controls, whereas curves in Figure 10 were derived from treatments involving optimum nitrogen additions.

Evaluation of data depicted in Figures 9 and 10 lead to the following conclusions:

1. When data are observed with respect to amount of sludge added to that decomposed, then with increasing sludge amounts, up to and including the 400 T/A addition rate, more was decomposed. As shown in Figure 9 when sludge was added at a rate of 400 T/A, about 120 T/A were utilized after 120 days incubation. With the 50 T/A addition less than 30 T/A were used. Effect of nitrogen used to enhance sludge breakdown is shown in Figure 10.

2. When data are reviewed in relation to completeness of breakdown, which is shown in curves having percent decomposition ordinates, the lower sludge levels were more completely utilized in 120 days. For example 50 T/A addition was about 55% utilized in 120 days in clay soil without nitrogen and about 62% utilized in sandy soil with optimum nitrogen. On the other hand, when sludge was added at a 400 T/A rate in clay soil without nitrogen about 26% was utilized in 120 days and about 37% utilized in sandy soil with nitrogen.

Data in Figure 11 again demonstrates the necessity of nitrogen supplement to enhance sludge disposal in the nitrogen deficient sandy soil or when exceptional high levels of nitrogen poor material, such as sludge, are being disposed.

As shown in Table 20, microbial activity after 120 days incubation of mixtures of test soils and various levels of sludge and nitrogen in clay soil results in a more than ten-fold increase in mold and bacterial numbers. This was noted in the 400 and 600 T/A treatments with or without nitrogen supplement. However, a far greater increase in microbial activity was noted in sandy soil. Here, mold was found to increase approximately 20 fold whereas bacterial numbers increased from approximately 1,000,000/gram soil to 563,000,000/gram.

TABLE 20

MICROBIAL ACTIVITY IN CLAY AND SANDY SOIL AFTER 120 DAYS INCUBATION

Sludge Addition Tons/Acre	Nitrogen Addition C:N	Clay Soil			Sandy Soil		
			Microorganisms/gr			Microorganisms/gr	
		pH	Molds (1×10^{-3})	Bacteria (1×10^{-6})	pH	Molds (1×10^{-3})	Bacteria (1×10^{-6})
0	0	5.7	183	14	6.8	7	1
100	0	6.8	170	29	6.9	93	26
200	0	6.8	173	230	7.3	58	23
400	0	6.6	853	230	7.3	66	69
600	0	7.0	1876	455	6.9	25	239
100	0	6.8	170	29	6.9	93	26
100	40:1	6.5	430	45	6.9	93	240
100	20:1	6.5	320	50	6.9	115	242
100	10:1	6.9	276	45	7.6	73	200
200	0	6.8	173	230	7.3	58	23
200	40:1	7.4	220	174	6.4	40	394
200	20:1	6.8	135	125	7.0	440	106
200	10:1	6.8	233	76	7.5	16	162
400	0	6.6	853	230	7.3	66	69
400	40:1	6.8	540	243	6.8	185	393
400	20:1	7.1	733	220	6.7	78	217
400	10:1	6.9	873	169	7.0	42	342
600	0	7.0	1876	455	6.9	25	239
600	40:1	6.7	577	655	7.2	148	317
600	20:1	6.7	3417	667	7.4	103	563
600	10:1	7.2	870	235	7.8	110	400

SECTION IX

GREENHOUSE STUDIES

Two air dry kilograms of Pasco sandy and Hesson clay soils were mixed with sludge to give field additions equivalent to 50, 100, 150, and 200 tons sludge per acre. Nitrogen as ammonium nitrate was supplemented and evenly distributed throughout sludge-soil mixtures in amounts to give sludge-nitrogen C:N ratios of 25:1 and 100:1.

Each of the mixtures were adjusted to 65 percent of their moisture holding capacity. According to pot culture technique of Stephenson and Schuster (3), aliquots of a nutrient solution, without nitrogen, but containing essential elements for plant growth were added to each pot.

All treatments were triplicated and pot placement randomized in the greenhouse. Ten sunflower seeds (Mammouth) were pressed into the soil contained in two quart milk cartons and covered to a depth of $\frac{1}{4}$ inch. Milk carton height was adjusted to one inch above soil level by trimming off excess. Within a week of seedling emergence, plants were selected for uniformity within each pot and culls removed by cutting stems at soil surface.

Plants were watered on an individual pot basis whenever soil surface appeared dry and leaves showed signs of incipient wilt. Maintaining the sunflower test plants under this water regime did not adversely affect plant growth, but did minimize unwanted leaching losses of water soluble components from the sludge-soil mixtures.

Above ground portions of test plants were harvested when developing flower buds first became visible. Yield was measured as fresh and dry weights. Test soils were removed from their containers, freed of residual roots, pulverized and replanted with sunflowers. A total of four crops were grown in each container of soil. Nutrient solution was applied to test soils at each planting. No additional nitrogen was added after the first crop. Length of growing period varied with season and ranged from 57 days to 76 days.

Experimental design and ranking (4) of yield data are shown in Table 21. Individual crop yields are shown in Table V in the Appendix. Sludge amendments of 100, 150,

TABLE 21

TREATMENT RANKING USING DUNCAN'S NEW MULTIPLE RANGE TEST

			Sunflower Dry Weight--Grams					
					Duncan's Ranking			
					Sandy Soil		Clay Soil	
Treatment No.	Sludge Tons/A	Additional Nitrogen	Sandy Soil Yield	Clay Soil Yield	Treatment No.	Yield	Treatment No.	Yield
1	0	0	1.88	4.63	17	0.93	17	0.35
2	50	0	1.78	2.35	16	1.48	16	0.50
3	100	0	1.98	1.85	2	1.78	3	1.85
4	150	0	1.93	2.15	1	1.88	15	1.95
5	200	0	1.90	2.18	5	1.90	4	2.15
6	50	25:1	2.70	6.35	4	1.93	5	2.18
7	50	100:1	1.93	3.65	7	1.93	2	2.35
8	100	25:1	5.08	7.75	3	1.98	11	3.45
9	100	100:1	2.13	3.65	13	1.98	13	3.60
10	150	25:1	4.98	6.68	9	2.13	7	3.65
11	150	100:1	2.28	3.45	11	2.28	9	3.65
12	200	25:1	5.13	6.15	15	2.35	14	4.45
13	200	100:1	1.98	3.60	6	2.70	1	4.63
14	0	(1)	3.03	4.45	14	3.03	12	6.15
15	0	(2)	2.35	1.95	10	4.98	6	6.35
16	0	(3)	1.48	0.50	8	5.08	10	6.68
17	0	(4)	0.93	0.35	12	5.13	8	7.75

(1), (2), (3) and (4) equivalent nitrogen as added in treatments 6, 8, 10 and 12 respectively.

Non-bracketed means are significantly different at 5% level.

and 200 T/A in both soils in combination with supplemental nitrogen at a C:N of 25:1 significantly improved sunflower growth over that of controls. Growth of sunflower, however, was markedly lower where sludge amendments were made without nitrogen. Yields were not improved with sludge addition and nitrogen at a C:N of 100:1.

Statistical comparison of growth curves in Figure 12 shows the magnitude of difference between 25:1 and 100:1 C:N ratios for the two soils.

The overall responses to treatments in sandy soil were quite similar to those in clay soil. However the yield levels were considerably different, i.e., mean yield in control clay soil (no sludge--no nitrogen) was 4.63 grams, whereas in control sandy soil (no sludge--no nitrogen) it was 1.88 grams. Incorporation of sludge at 100 T/A and a C:N of 25:1 in clay soil increased mean crop yield to 7.75 grams, a 1.7 fold increase. Conversely with sandy soil receiving equivalent sludge and nitrogen, the increase in yield was 5.08 grams or a 2.7 fold increase.

When various levels of sludge were added to clay soil and no supplemental nitrogen provided, no significant differences in crop yield were obtained even though these yields ranged from 1.85 grams to 2.35 grams and were approximately one half the 4.63 gram yield obtained with control soil. A similar crop yield reduction resulted when nitrogen was added without sludge.

Sandy soil without sludge responded more favorably to nitrogen additions than did the clay soil. In sandy soil, as shown in Table 21, nitrogen additions to control soil (treatments 14 and 15) significantly increased sunflower yields. More nitrogen (treatments 16 and 17) decreased yield.

Figures 2A, 3A, 4A and 5A in Appendix present photographs of each harvest before sunflowers were cut down, dried and weighed. Numbers under each container correspond to treatment outlined in the tables.

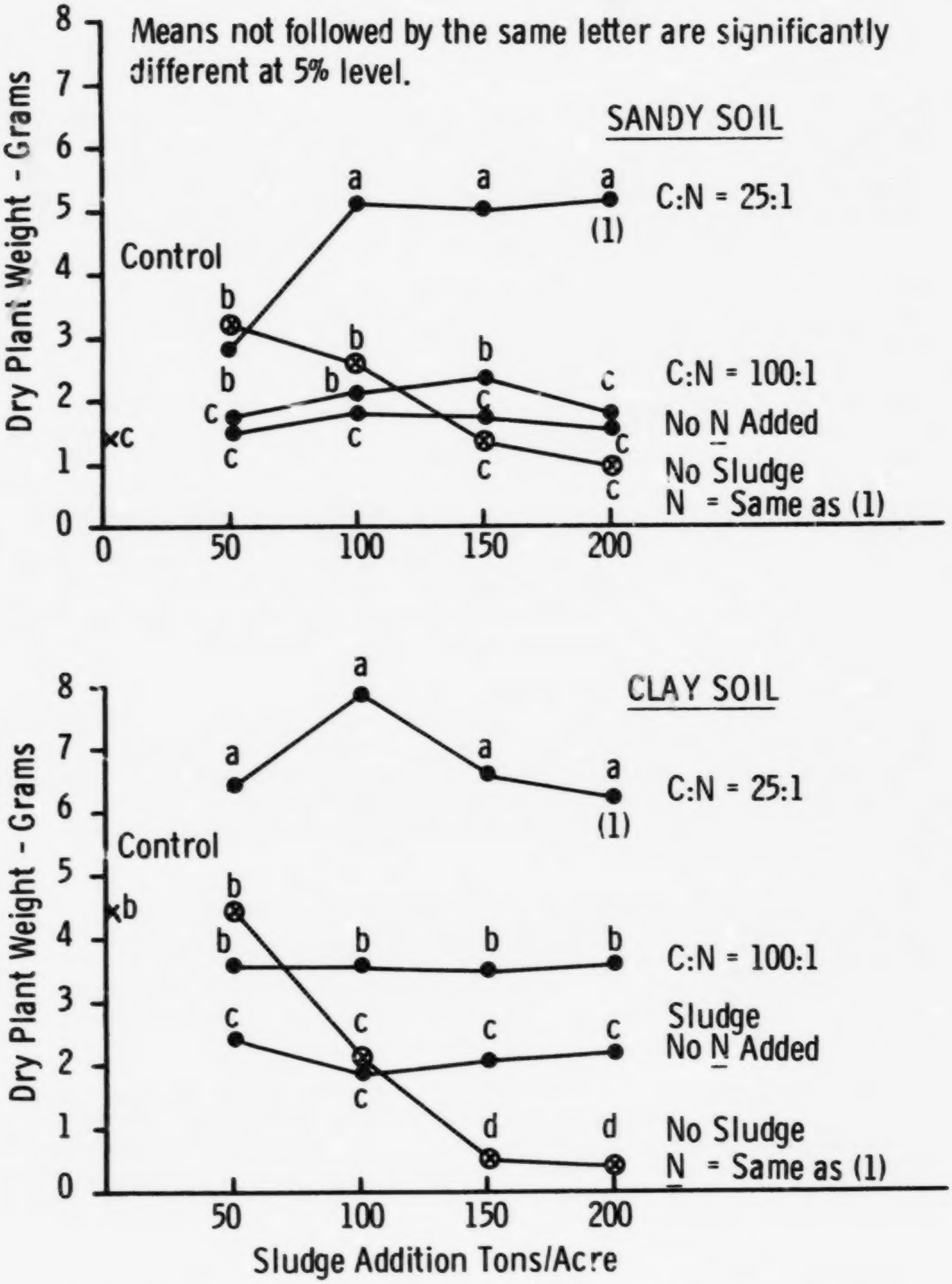


FIGURE 12. EFFECT OF NITROGEN ADDITION AND SLUDGE ON SUNFLOWER YIELD.

SECTION X

FIELD PLOT STUDIES

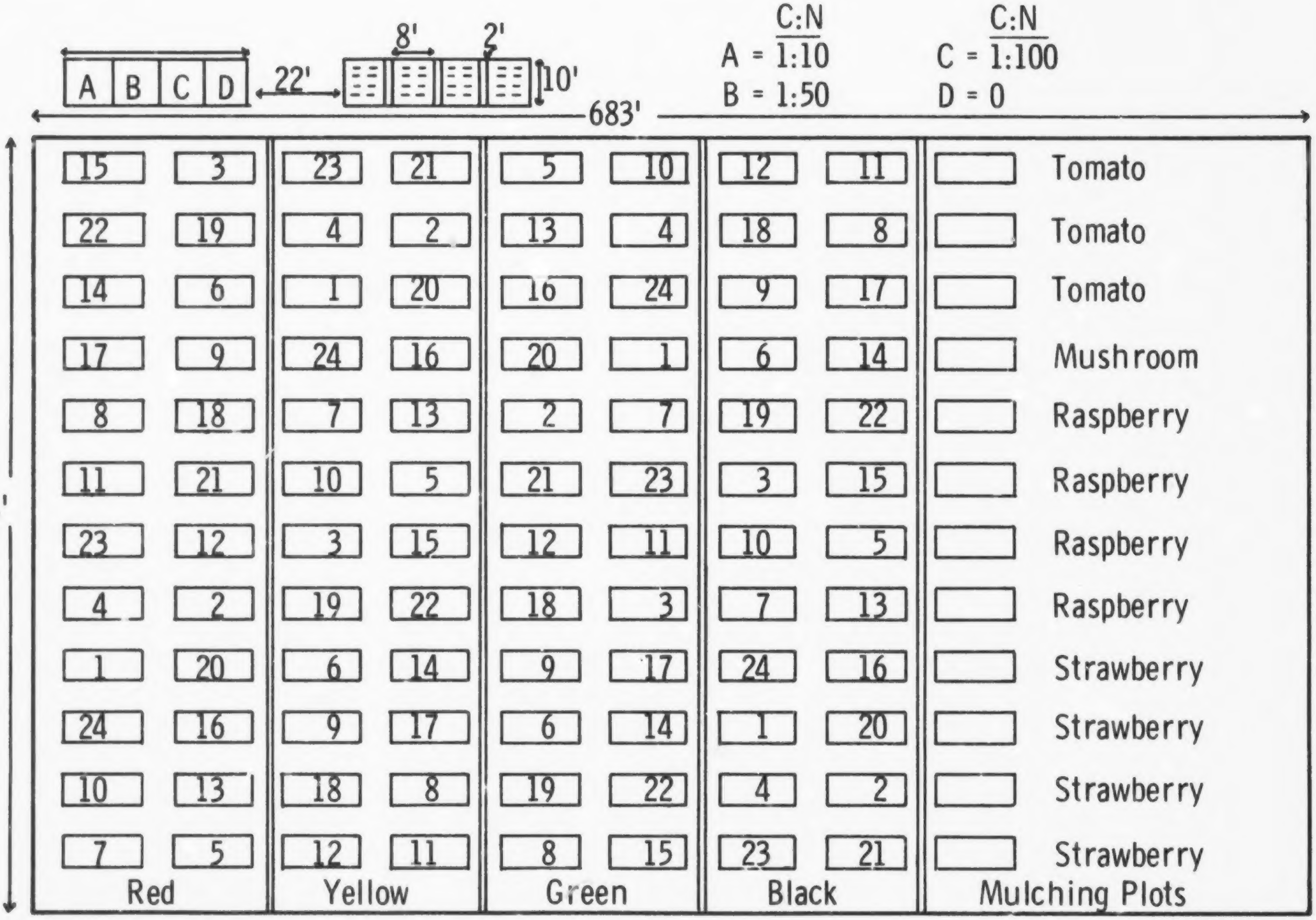
A five acre field about three miles from the clarifier was leased for the study. Historically it was in permanent pasture of grass and clover for ten years and of only fair productivity. The Hesson clay topsoil and brown-yellow silty clay subsoil of this area has a marked tendency toward clod formation when depleted of organic constituents.

The field was plowed in July of 1969 to a depth of 6 inches. During the summer and fall months the plots were periodically disced to control weeds. Ninety-six plots, measuring 10 by 38 feet, were layed out with the long sides at right angles to the slight slope of the field. Each treatment was replicated four times and each plot was divided into 4 subplots to permit evaluation of nitrogen additions on crop growth and sludge decomposition. Three rates of nitrogen fertilization were used based on carbon:nitrogen (C:N) ratios of 10:1, 50:1 and 100:1. The experimental design, location of randomized plots, position of subplots with respect to nitrogen additions and crop locations as well as row placement are shown in Figure 13. An aerial photograph in Figure 14 shows plot location and alignment. The rates and frequency of sludge application and the number of seasons crops were cultivated are shown in Table 22. The main disposal designs studied were: (A) Tolerance, (B) Yearly Amendment and (C) Disposal.

The Tolerance approach to sludge utilization was planned to determine the effect of a single incorporation of high levels of undecomposed sludge on the 1970 crops of sweet corn and snap beans. Recropping these plots in 1971 and 1972 was planned so that there would be a time interval for disappearance of potential sludge induced phytotoxicity.

Sludge addition in the Yearly Amendment objective was made in a manner simulating farmer use of crop residues or cover crops. Beans and corn were grown on these plots each of the three years.

The most efficient land use and maximum rate of sludge disposal would probably be achieved under the Disposal objective. Yearly sludge incorporation into these plots was carried out over the three year period of the study with test crops of beans and corn cultivated in the 1972 season only.



Red		Yellow		Green		Black		Mulching Plots	
15	3	23	21	5	10	12	11		Tomato
22	19	4	2	13	4	18	8		Tomato
14	6	1	20	16	24	9	17		Tomato
17	9	24	16	20	1	6	14		Mushroom
8	18	7	13	2	7	19	22		Raspberry
11	21	10	5	21	23	3	15		Raspberry
23	12	3	15	12	11	10	5		Raspberry
4	2	19	22	18	3	7	13		Raspberry
1	20	6	14	9	17	24	16		Strawberry
24	16	9	17	6	14	1	20		Strawberry
10	13	18	8	19	22	4	2		Strawberry
7	5	12	11	8	15	23	21		Strawberry

FIGURE 13 EXPERIMENTAL PLOT LAYOUT FOR SLUDGE UTILIZATION PROJECT.

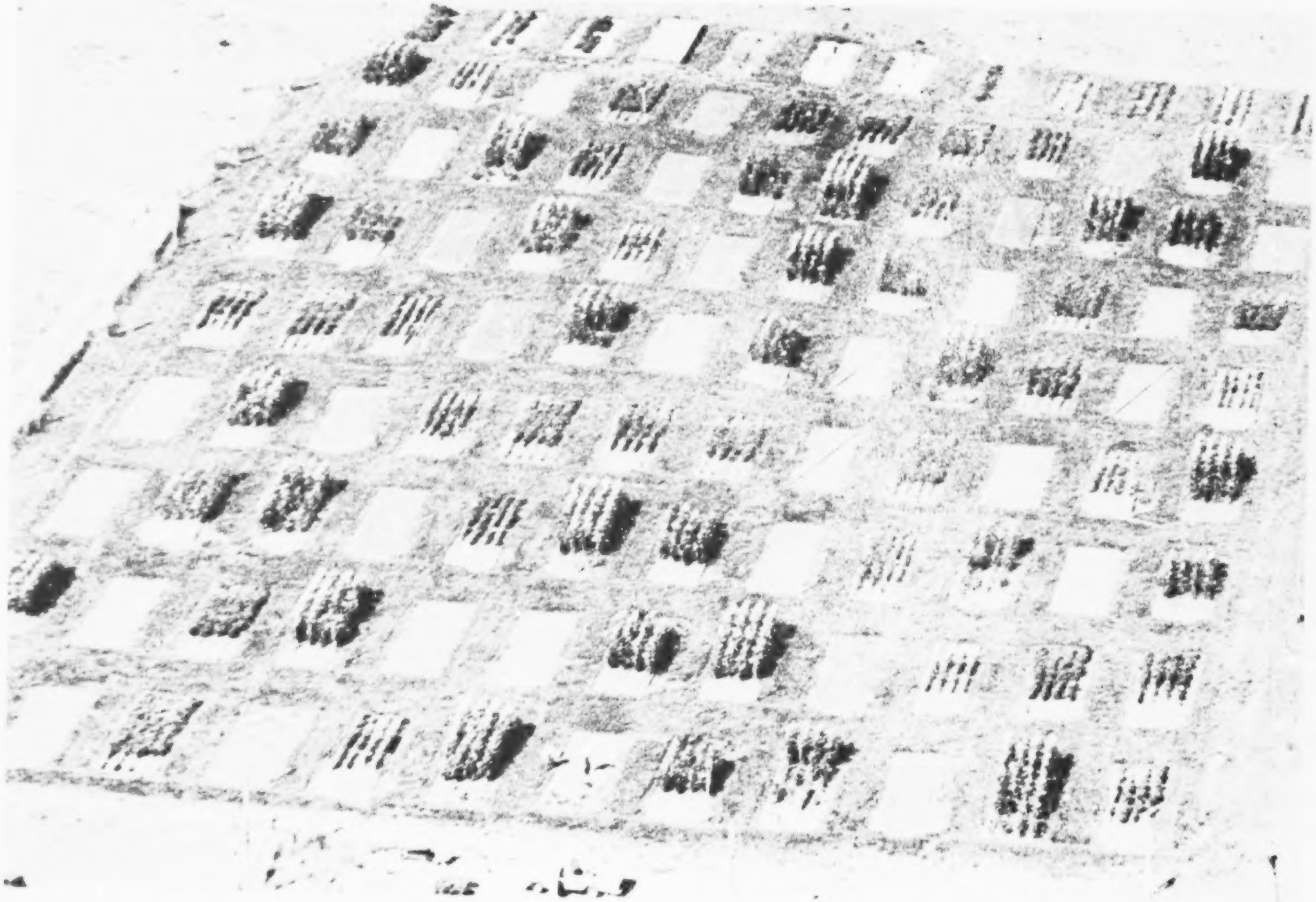


FIGURE 14. AERIAL PHOTOGRAPH OF SLUDGE AMENDED PLOTS.

TABLE 22

EXPERIMENTAL DESIGN FOR SLUDGE DISPOSAL FIELD TRIALS

A. Tolerance - Add sludge once only, in fall; plant crop each spring.

			Split Plot C:N			
			A	B	C	D
Plot No.	Addition, Tons/Acre	Crop	Lbs N 10:1	Lbs N 50:1	Lbs N 100:1	Lbs N 0
1	0	Corn	91.6	18.3	9.2	0
2	200	Corn	91.6	18.3	9.2	0
3	400	Corn	183.3	36.7	18.3	0
4	600	Corn	274.9	55.0	27.5	0
5	0	Beans	91.6	18.3	9.2	0
6	200	Beans	91.6	18.3	9.2	0
7	400	Beans	183.3	36.7	18.3	0
8	600	Beans	274.9	55.0	27.5	0

B. Yearly Amendment - Add sludge each fall; plant crop each spring.

9	0	Corn	45.8	9.2	4.6	0
10	100	Corn	45.8	9.2	4.6	0
11	200	Corn	91.6	18.3	9.2	0
12	400	Corn	183.3	36.7	18.3	0
13	0	Beans	45.8	9.2	4.6	0
14	100	Beans	45.8	9.2	4.6	0
15	200	Beans	91.6	18.3	9.2	0
16	400	Beans	183.3	36.7	18.3	0

C. Disposal - Add sludge each fall; work in during summer; plant crop after 3 years.

17	0	Corn	45.8	9.2	4.6	0
18	100	Corn	45.8	9.2	4.6	0
19	200	Corn	91.6	18.3	9.2	0
20	400	Corn	183.3	36.7	18.3	0
21	0	Beans	45.8	9.2	4.6	0
22	100	Beans	45.8	9.2	4.6	0
23	200	Beans	91.6	18.3	9.2	0
24	400	Beans	183.3	36.7	18.3	0

Sludge for the initial amendments was collected after dewatering by vacuum filter and stored adjacent to the experimental plots in late spring of 1969. Application and soil incorporation of this 20% consistency sludge was difficult. The capability of dewatering sludge to 38% consistency was realized with installation of the incinerator and Reitz press. The drier sludge was used for the 1970 and 1971 amendments and was far superior to the 20% consistency material with respect to ease of handling, application and incorporation.

Sludge incorporated in 1969 and 1970 equivalent to a total of 800 T/A to the Yearly Amendment and the Disposal plots altered their surface composition to essentially that of sludge. The final sludge application scheduled for September 1971 could not be made with power equipment as the spongy or marsh-like consistency of the 400 T/A plots would not support weight of the farm equipment. Therefore the third 400 T/A amendment to Yearly Amendment and Tolerance plots was canceled.

Except for the difficulties encountered in 1969 with application and rotovation of the 20 percent consistency sludge and those involving successive yearly additions of 400 T/A, standard farm equipment worked well in mixing sludge with soil. Two tractors were used, one to pull an International Harvester Corporation manure spreader and the other, a 45 H.P. Ford diesel, with a Wagner loader attachment, was used to load sludge on the spreader. The Ford tractor was also equipped with a heavy duty E-60 Howard Rotovator.

Weight/volume relationships of the 20 and 38% solids sludge were used to determine the plot requirements. The 20% solids required two and the 38% solids required three spreader loads to give a 100 T/A rate.

Uniform distribution of sludge was accomplished by repeated passes over the length of the plot with no more than 2 spreader loads. The resulting 4 to 5 inch sludge layer was then rototilled into the soil.

Plot perimeters were aligned and surfaces leveled by hand tools and the initial 1/3 of the specified nitrogen was applied in the form of 34% ammonium nitrate. Subsequent applications of nitrogen were made in February and late

March. During the first year of study in which 10:1 C:N ratios were part of the experimental design, the ammonium nitrate was applied in four portions with the final portion spread May 1. A 0-20-20 fertilizer application (N-P-K) at a 500 pound per acre rate was made to all plots in line with the general agricultural practices for farm land in this area.

Weed growth during fall-winter fallow was controlled with sprays of Paraquat CL at 2 quarts per acre.

Plots were rototilled as early in May of each year as soil conditions would permit using a 4 H.P. hand operated tiller. Use of the small rototiller was necessary for cultivation of individual subplots to avoid intermixing of subplots of different nitrogen levels. In 1969 only, preplanting herbicide treatments were made on all plots for weed grasses with Eptam 60 at 2 quarts per acre. An additional preplant treatment of corn plots was made for broadleaf weed control with Atrazine at 2.5 lbs per acre.

Uniform non-skip delivery of Tendercrop variety bean seeds into furrows was accomplished with a planter made of a plastic wide neck funnel inserted into a 3¼ ft length of 3/4 in. electrical conduit. Golden Jubilee variety corn was planted in hills about 1 foot apart using a commercial hand planter set to deliver 3 to 4 seeds.

Plant stands were thinned when they were 3-4 inches high to a spacing of 3-4 inches in the case of beans and 1 foot spacing or 1 plant per hill in the case of corn.

Plots were irrigated at 10 to 12 day intervals using 7 overhead sprinklers each of which delivered about 5 gallons per minute. Irrigation for 3-4 hours applied about 0.8 in. water at which time the sprinklers were moved to the next area. The need for water was determined by the condition of soil in the control plots as the soil in these plots was consistently depleted of moisture more rapidly than sludge amended plots.

Weed growth during the 1970 growing season was minimal as a result of preplanting herbicide treatments and discing procedures. No special attention was given plots other than irrigation as needed. Slight herbicidal damage to corn in the form of leaf burn and stunting did occur and preplant chemical weed control measures were eliminated in subsequent years. With no herbicide used prior to seeding or as a pre-emergence treatment, weed growth in non-sludge and low rate sludge plots was extensive even before emergence of corn and bean plants. Hand cultivation and between row low pressure spray applications of Paraquat CL using a hand sprayer were effective control measures. Herbicide was also applied to the perimeter of plots to reduce mid and late season encroachment of weeds from turf areas separating the plots.

Only mature pods and mature full ears were picked on the first harvest date of each crop. The randomly occurring unfilled ears of corn with less than 50% kernel development were not included in yield data of final harvest.

The influence of sludge amendments on corn and bean growth was determined 1 month before harvest for each of the 3 crop years as Total Quality Scores (TQS). As shown on the following page, the TQS is the sum of numerical ratings assigned to five of the following growth criteria with a maximum score of 20 indicative of near perfect growth and development:

Growth Criteria	Numerical Rating				
	4	3	2	1	0
Seedling Emergence, %	95-100	75-94	50-74	25-49	0-24
General Appearance	Very Good	Good	Fair	Poor	Very Poor
Color	Dark Green	Light Green	Yellow Green	Yellow	Chlorotic
Leaf Abnormalities	None	Few	Moderate	Many	Very Many
Average Crop Height, cm					
Corn	More Than 300	200-300	100-200	50-100	0-50
Beans	More Than 40	30-40	20-30	10-20	0-10

Yields from subplots on the harvest dates were made in pounds and tenths of pounds. A portable Homs beam scale was used to weigh harvested crops contained in plastic bags.

TOLERANCE DESIGN

Plot Quality Evaluation, 1970

Detailed data concerning total quality scores and yields are shown in Tables VI, VII, VIII in the Appendix for the Tolerance Design portion of the field plot studies. For convenience summaries of these data are given in Tables 23, 24 and 25.

TABLE 23

STATISTICAL RANKING ACCORDING TO DUNCAN'S NEW MULTIPLE RANGE TEST FOR CORN YIELD, TOLERANCE DESIGN FOR 1970, 1971, 1972

1970				1971				1972			
Plot No.	Sludge Tons/A	Nitrogen Addition	Yield Lbs	Plot No.	Sludge Tons/A	Nitroge. Addition	Yield Lbs	Plot No.	Sludge Tons/A	Nitrogen Addition	Yield Lbs
2A	200	10:1	0	1A	0	91.6#	1.5	1A	0	91.6#	12.6
3A	400	10:1	0	1B	0	18.3#	20.2	1B	0	18.3#	25.7
4A	600	10:1	0	1D	0	0	26.3	1D	0	0	28.4
1A	0	91.6#	1.9	1C	0	9.2#	27.3	3D	400	0	28.9
4D	600	0	21.5	2A	200	10:1	34.0	2A	200	10:1	30.6
1B	0	18.3#	22.8	2D	200	0	34.8	2D	200	0	32.7
3D	400	0	24.7	2C	200	100:1	35.0	1C	0	9.2#	33.3
4B	600	50:1	26.4	4A	600	10:1	35.7	2B	200	50:1	35.0
2B	200	50:1	32.7	2B	200	50:1	44.1	2C	200	100:1	39.0
1C	0	9.2#	33.5	4D	600	0	46.4	3A	400	10:1	41.7
4C	600	100:1	34.5	4B	600	50:1	46.5	3B	400	50:1	42.8
3B	400	50:1	41.4	3D	400	0	47.3	3C	400	100:1	43.4
2D	200	0	46.9	3A	400	10:1	47.6	4C	600	100:1	45.6
3C	400	100:1	47.3	4C	600	100:1	49.3	4D	600	0	46.8
1D	0	0	55.5	3C	400	100:1	51.5	4B	600	50:1	48.6
2C	200	100:1	69.9	3B	400	50:1	52.9	4A	600	10:1	50.9

TABLE 24

STATISTICAL RANKING ACCORDING TO DUNCAN'S NEW MULTIPLE RANGE TEST FOR BEAN YIELDS, TOLERANCE DESIGN FOR 1970, 1971, 1972

1970				1971				1972			
Plot No.	Sludge Tons/A	Nitrogen Addition	Yield Lbs	Plot No.	Sludge Tons/A	Nitrogen Addition	Yield Lbs	Plot No.	Sludge Tons/A	Nitrogen Addition	Yield Lbs
5A	0	91.6#	0	5A	0	91.6#	0.3	5A	0	91.6#	0.4
7A	400	10:1	0	6A	200	10:1	0.3	6A	200	10:1	0.9
8A	600	10:1	0	7A	400	10:1	1.8	5B	0	18.3#	8.8
6A	200	10:1	0.1	8A	600	10:1	2.6	5D	0	0	17.9
7B	400	50:1	1.4	5B	0	18.3#	4.6	5C	0	9.2#	22.2
8B	600	50:1	2.7	5C	0	9.2#	13.1	7D	400	0	27.9
8D	600	0	2.8	5D	0	0	17.4	6B	200	50:1	28.5
5B	0	18.3#	3.1	6B	200	50:1	18.4	7A	400	10:1	30.1
7C	400	100:1	5.0	7B	400	50:1	19.3	8A	600	10:1	30.5
8C	600	100:1	5.4	7D	400	0	20.1	7C	400	100:1	30.7
6B	200	50:1	5.8	8D	600	0	20.1	6C	200	100:1	31.2
7D	400	0	7.3	6D	200	0	21.2	6D	200	0	31.5
5C	0	9.2#	17.1	6C	200	100:1	23.4	7B	400	50:1	33.7
6D	200	0	21.8	8B	600	50:1	24.4	8D	600	0	38.5
6C	200	100:1	26.1	7C	400	100:1	26.8	8B	600	50:1	39.1
5D	0	0	32.2	8C	600	100:1	27.4	8C	600	100:1	42.7

Any two values not bracketed by same line are significantly different; any two values bracketed are not significantly different at 5% level.

TABLE 25

SUMMARY--TOLERANCE DESIGN

Sludge T/A	Nitrogen Addition lbs N	Total Quality Scores						Yield, lbs/sub-plot							
		Corn			Beans			Corn				Beans			
		1970	1971	1972	1970	1971	1972	1970	1971	1972	Total	1970	1971	1972	Total
0	91.6	0	8	7	1	--*	3	1.9	1.5	12.6	16.0	0	0.3	0.4	0.7
0	18.3	14	16	14	9	--	10	27.8	20.2	25.7	73.7	3.1	4.6	8.8	16.5
0	9.2	15	16	17	11	--	14	33.5	27.3	33.3	94.1	17.1	13.1	22.2	52.4
0	0	18	16	16	17	--	15	55.5	26.3	28.4	110.2	32.2	17.4	17.9	67.5
	C:N														
200	10:1	2	18	18	6	--	6	0	34.0	30.6	64.6	0.1	0.3	0.8	1.2
200	50:1	16	18	17	12	--	17	32.7	44.1	35.0	111.8	5.8	18.4	28.5	52.7
200	100:1	18	19	17	14	--	17	69.9	35.0	39.0	143.9	26.1	23.4	31.2	80.7
200	0	12	17	16	10	--	17	46.9	34.8	32.7	114.4	21.8	21.2	31.5	74.5
400	10:1	0	19	18	0	--	16	0	47.6	41.7	89.3	0	1.8	30.1	31.9
400	50:1	12	19	18	10	--	17	41.4	52.9	42.8	137.1	1.4	19.3	33.7	54.4
400	100:1	16	19	17	12	--	18	47.3	51.5	43.4	142.2	5.0	26.8	30.7	62.5
400	0	9	19	16	9	--	17	24.7	47.3	28.9	100.9	7.3	20.1	27.9	55.3
600	10:1	0	19	20	0	--	16	0	35.7	50.9	86.6	0	2.6	30.5	33.1
600	50:1	12	19	20	11	--	19	26.4	46.5	48.6	121.5	2.7	24.4	39.1	66.2
600	100:1	16	19	20	11	--	19	34.5	49.3	45.6	129.4	5.4	27.4	42.7	75.5
600	0	7	19	20	8	--	18	21.5	46.4	46.8	114.7	2.8	20.1	38.5	61.4

*Total quality scores not observed in 1971.

Sludge amendments to field plots in the fall of 1969 at 200, 400 and 600 T/A resulted in soil conditions that were unfavorable to late-season growth of the 1970 corn crop. The moderately stunted and yellow plants that developed on plots receiving even the minimum amendment of 200 T/A were rated with a Total Quality Score (TQS) of 12 compared with the TQS of 18 given seedlings on comparable control plots. However, plots fertilized with nitrogen at a 100:1 carbon-nitrogen ratio as shown in Table 25 produced corn stands with TQS of 18 that were comparable to controls.

Corn yields in 1970 from plots amended with sludge but not fertilized with nitrogen were from 14 to 60 percent lower than yields from the untreated (no nitrogen fertilization) control plots. Nitrogen additions at C:N of 100:1 increased the corn production of all sludge amended plots with the highest yield in 1970 harvested from the 200 T/A plots supplemented with nitrogen at the C:N of 100:1. Yield of 55.5 lbs from corn grown on untreated control plots was approximately 20 percent less than the nearly 70 lbs obtained from the 200 T/A sludge-nitrogen plots. Yields from control plots were reduced by all of the tested levels of nitrogen fertilization.

Soil conditions in plots at all levels of sludge without nitrogen supplement were highly unsatisfactory for growth of the bean test crop in 1970. Low TQS of 10, 9, and 8 were obtained at rates of 200, 400 and 600 T/A. Nitrogen fertilization equivalent to the C:N of 100:1 offset some of the adverse growth conditions, but even at the optimum sludge-nitrogen C:N of 100:1, bean growth on the 200 T/A plots was rated 14 compared with the 17 for non-nitrogen fertilized control plots.

Bean yields in 1970 of practical significance were obtained only from crops grown on the 200 T/A sludge amended plots. The phytotoxic properties of sludge even at the low 200 T/A rate resulted in an approximate 1/3 lower yield than that obtained from comparable controls. Nitrogen additions to amended plots at apparent optimum C:N of 100:1 did not return yield to the level obtained from the unamended, and non-nitrogen fertilized plots.

Plot Quality Evaluation--1971

Growth and development of corn test plants on all plots amended with sludge only and sludge-nitrogen combinations was superior to that on control plots as shown by TQS. The unfavorable soil conditions associated with the 400 and 600 T/A amendments observed in the 1970 corn crop were totally absent in the 1971 corn crop and TQS of 19 resulted even at the excessive nitrogen level based on the C:N of 10:1. In addition the TQS of corn at the 200 T/A amendment was lower than those at the 400 and 600 T/A in the 1971 crop, just the reverse of the TQS of corn observed in 1970. These latter data suggest that peak productivity of the 200 T/A amended plots was in 1970 and the 400 and 600 T/A plots respectively have reached or are approaching their stage of maximum production.

The corn yields in 1971 paralleled the TQS with production from all sludge amended plots greater than those of controls. Maximum harvests were obtained from the 400 T/A sludge addition fertilized at the C:N of 50:1 and 100:1. Yields lend support to the concept that peak production is related to both the rate of sludge amendment as well as the elapsed time between incorporation and plot use for crop culture.

TQS observations were not made for the 1971 bean test crop. Bean yields in 1971 from the three sludge amendment rates alone and in combination with nitrogen at C:N of 50:1 and 100:1 were all greater than those from control plots. The shift in peak yield production from low to high sludge amendment with successive (years) corn crops is not nearly so discernible with the bean test crop. The relationship does occur however with peak yields at 200 T/A in 1970 and at 600 T/A in 1972.

Plot Quality Evaluation--1972

In the third year following the single sludge application to field plots, growth of the corn test crop was most favored by the 600 T/A amendment. Near optimum and essentially identical growth responses 1 month before harvest resulted in TQS of 20 for all conditions relative to nitrogen supplements. In contrast, control or unamended plots produced corn rated 7 and 16 in the case of the high and no nitrogen supplemented plots, respectively.

Corn yields from the 1972 crops were greatest with the 600 T/A sludge amendment and were not influenced by nitrogen fertilization. As shown in Table 23 no statistical differences were noted in yields from corn grown on nitrogen supplemented subplots and comparable controls.

Statistical data in Table 24 also show that growth of beans in 1972, as with corn, was favored by the 600 T/A amendment. The highest TQS were obtained with nitrogen additions at the C:N of 50:1 and 100:1 and with no nitrogen supplement.

The 1972 bean yields from sludge amended plots exceeded those from controls. High, but non-significantly, different yields were produced both with nitrogen supplements at C:N of 50:1 and 100:1 and without the nitrogen additive. Those data shown in Table 25 indicate nitrogen added at the time of sludge incorporation, which was necessary for the first and second crop years, was not required for high yields in the third year.

The quality of land used in the present study is shown by the corn and bean yields obtained from the unamended control plots. The summary Table 25 shows bean yields from non-nitrogen control plots in 1970 of 32.2 lbs decreased to a level of only 17 lbs or so in the two following years and corn production of 55.5 lbs in 1970 decreased to 26.3 lbs in 1971 and 28.3 lbs in 1972. Supplemental nitrogen alone was not sufficient to offset this yield reduction for either crop.

During the initial or 1970 bean crop harvest, observations indicated a more rapid development of pods to the fresh or processing market stage on the sludge amended plots. Harvests in the following two years were made at one week intervals as pods reached the stage suitable for table use. Peak yields were obtained in the second picking from plots amended with 600 T/A, compared with the even distribution of control yields over the 2 and 3 harvest dates. As shown in Table 26 with the 1972 crop, all 400 T/A plots, except the sludge-nitrogen combination at the 10:1 C:N, and all 600 T/A plots produced peak yields of fresh market quality beans one week earlier than did the untreated or nitrogen amended control plots.

TABLE 26

EFFECT OF SLUDGE ON BEAN MATURITY RATE WHEN GROWN ON TOLERANCE PLOTS

Plot No.	Sludge Tons/A	Nitrogen Addition Lbs-N	Picking Dates--1971 9/2 Lbs	9/9 Lbs	9/19 Lbs	Yield Lbs	Picking Dates--1972 9/8 Lbs	9/14 Lbs	9/24 Lbs	9/28 Lbs	Yield Lbs
5A	0	91.6	0	0.1	0.2	0.3	0	0.1	0	0.1	0.4
5B	0	18.3	0.3	1.5	2.8	4.6	1.1	3.5	1.6	2.6	8.8
5C	0	9.2	1.2	4.7	7.3	13.1	6.2	9.1	4.3	2.7	22.2
5D	0	0	1.5	8.2	7.8	17.4	6.3	5.3	3.9	2.4	17.9
		C:N									
6A	200	10:1	0	0	0	0	0	0.1	0.1	0.7	0.8
6B	200	50:1	1.5	6.2	10.7	18.4	9.8	9.2	0.9	2.7	28.5
6C	200	100:1	2.3	8.4	12.3	23.4	9.7	9.4	8.1	4.1	31.2
6D	200	0	2.8	8.5	9.9	21.2	10.6	9.0	8.1	3.9	31.5
7A	400	10:1	0.1	0.2	1.6	1.8	9.2	10.8	6.7	3.5	30.2
7B	400	50:1	2.1	9.5	7.8	19.3	12.6	9.3	7.6	4.2	33.7
7C	400	100:1	3.0	11.3	12.4	26.8	11.5	8.1	7.6	3.5	30.7
7D	400	0	2.8	8.2	9.1	20.7	9.9	8.4	5.1	4.5	27.9
8A	600	10:1	0.3	0.4	1.9	2.6	10.5	8.8	8.4	2.9	30.5
8B	600	50:1	2.7	15.0	6.6	24.4	14.7	8.4	12.4	3.6	39.1
8C	600	100:1	2.4	14.6	10.3	27.4	15.5	11.1	12.5	3.6	42.7
8D	600	0	1.7	11.1	7.3	20.1	12.8	10.1	11.1	4.5	38.5

Data included in each blocked area across the page are not significantly different from each other but are significantly different from values outside blocked area.

YEARLY AMENDMENT DESIGN

Plot Quality Evaluation--1970

Detailed data concerning total quality scores and yields are shown in Tables VI, IX and X in the Appendix for the Yearly Amendment Design portion of this study. For convenience summaries of these data are given in Tables 27, 28 and 29 in the text.

Results and discussion concerning the Yearly Amendments of 200 and 400 T/A are contained in the Tolerance portion of the report since during the first crop year at these common rates of amendment, no difference existed in the two disposal approaches.

The 1970 corn stands on plots amended with sludge at 100 T/A were equivalent to or slightly better than those of controls with TQS of 19 and 18 respectively. These low levels of amendment were not phytotoxic and did not cause a nitrogen deficiency in test plants. Yield was not altered by the 100 T/A sludge addition, and tilth and color of soil were noticeably improved over those of controls.

As shown in Table 29 Total Quality Scores of 20 for bean crop on the 100 T/A amended plots compared with the 17 for controls reflects the near ideal soil conditions resulting from the organic amendment. Data in Table 28, however show that only a slight yield increase in the 100 T/A amendment occurred and is not statistically different from yield obtained from the control (no sludge-no nitrogen).

Plot Quality Evaluation--1971

Soil conditions of Yearly Amendment plots were markedly altered by the second sludge amendment and at the 200 and 400 T/A rates resulted in delayed or pre-emergence seedling death, light green leaves indicating nitrogen deficiency, and marked stunting of the corn test crop. Successive annual additions of the 100 T/A amendment in combination with nitrogen at C:N of 50:1 in contrast produced favorable soil conditions and corn stands superior to those of control plots as shown by the TQS of 19 compared with 18 for controls.

TABLE 27

STATISTICAL RANKING ACCORDING TO DUNCAN'S NEW MULTIPLE RANGE TEST FOR CORN YIELD, YEARLY AMENDMENT DESIGN FOR 1970, 1971, 1972

1970				1971				1972			
Plot No.	Sludge Tons/A	Nitrogen Addition	Yield Lbs	Plot No.	Sludge Tons/A	Nitrogen Addition	Yield Lbs	Plot No.	Sludge Tons/A	Nitrogen Addition	Yield Lbs
12A	400	10:1	0	9A	0	18.3#	0	9A	0	18.3#	0
9A	0	45.8#	3.0	10D	100	0	0.2	11D	200	0	2.6
11A	200	10:1	4.0	11C	200	200:1	0.5	11C	200	200:1	3.1
10A	100	10:1	10.3	11D	200	0	0.5	11B	200	100:1	4.3
12D	400	0	27.6	12D	400	0	1.2	11A	200	50:1	6.1
12B	400	50:1	28.0	12C	400	200:1	3.6	9B	0	9.2#	6.9
9B	0	9.2#	29.9	12B	400	100:1	3.7	10D	100	0	21.4
11B	200	50:1	39.3	12A	400	50:1	5.8	10C	100	200:1	27.5
12C	400	100:1	42.0	11B	200	100:1	6.0	12D*	--	--	27.8
9C	0	4.6#	42.8	11A	200	50:1	6.4	12B*	--	--	28.3
11C	200	100:1	47.5	10C	100	100:1	13.4	9D	0	0	30.8
10B	100	50:1	49.1	10A	100	50:1	31.6	9C	0	4.5#	32.0
9D	0	0	51.8	9D	0	0	32.8	12A*	--	--	32.9
10C	100	100:1	52.4	9C	0	4.5#	40.3	12C*	--	--	35.3
11D	200	0	54.1	10B	100	100:1	40.5	10A	100	50:1	37.8
10D	100	0	55.8	9B	0	9.2#	47.2	10B	100	100:1	39.8

TABLE 28

STATISTICAL RANKING ACCORDING TO DUNCAN'S NEW MULTIPLE RANGE TEST FOR BEAN YIELDS, YEARLY AMENDMENT DESIGN FOR 1970, 1971, 1972

1970				1971				1972			
Plot No.	Sludge Tons/A	Nitrogen Addition	Yield Lbs	Plot No.	Sludge Tons/A	Nitrogen Addition	Yield Lbs	Plot No.	Sludge Tons/A	Nitrogen Addition	Yield Lbs
15A	200	10:1	0	13A	0	18.3#	0	13A	0	18.3#	0
16A	400	10:1	0	16D	400	0	0	15A	200	50:1	0.6
13A	0	45.8#	0.1	15A	200	50:1	0.3	15C	200	200:1	1.2
14A	100	10:1	0.2	14A	100	50:1	0.9	15B	200	100:1	1.7
16B	400	50:1	1.6	16C	400	200:1	0.9	15D	200	0	1.8
16C	400	100:1	4.8	16B	400	100:1	1.5	14A	100	50:1	2.1
16D	400	0	6.0	15D	200	0	2.1	13B	0	9.2#	4.5
15B	200	50:1	10.4	16A	400	50:1	3.8	16D*	--	--	4.7
13B	0	92#	17.9	14D	100	0	6.7	14D	100	0	5.3
14B	100	50:1	27.3	15B	200	100:1	7.5	16B*	--	--	6.1
13C	0	46#	33.2	13B	0	9.2#	7.9	16C*	--	--	6.7
15D	200	0	34.3	15C	200	200:1	8.1	13C	0	4.6#	9.2
15C	200	100:1	36.0	14C	100	200:1	15.9	16A*	--	--	16.0
13D	0	0	37.2	14B	100	100:1	19.0	14C	100	200:1	18.7
14D	100	0	40.3	13D	0	0	22.6	14B	100	100:1	19.3
14C	100	100:1	41.4	13C	0	4.6#	24.5	13D	0	0	27.4

*400 T/A addition third year was not possible -- yield values not comparable.

Any two values not bracketed by same line are significantly different; any two values bracketed are not significantly different at 5% level.

TABLE 29

SUMMARY--YEARLY AMENDMENT DESIGN

Sludge T/A	Nitrogen Addition lbs	Total Quality Score						Yield, lbs/subplot					
		Corn			Beans			Corn			Beans		
		1970	1971	1972	1970	1971	1972	1970	1971	1972	1970	1971	1972
0	45.8	0	14	0	0	--*	0	3.0	0	0	0.1	0	0
0	9.2	14	18	9	9	--	6	29.9	47.2	6.9	17.9	7.9	4.5
0	4.6	15	15	13	11	--	10	42.8	40.3	32.0	33.2	24.5	9.2
0	0	18	16	15	17	--	10	51.8	32.8	30.8	37.2	22.6	27.4
	C:N												
100	10:1	7	17	14	6	--	7	10.3	31.6	37.8	0.2	0.9	2.1
100	50:1	16	19	10	13	--	14	49.1	40.5	39.8	27.3	19.0	19.3
100	100:1	19	17	7	16	--	12	52.4	13.4	27.5	41.4	15.9	18.7
100	0	19	12	8	20	--	6	55.8	0	21.4	40.3	6.7	5.3
200	10:1	2	13	6	6	--	5	0	0	0	0	0	0
200	50:1	16	14	4	12	--	6	39.3	6.0	4.3	10.4	7.5	1.7
200	100:1	18	14	3	14	--	6	47.5	0.5	3.1	36.0	8.1	1.2
200	0	12	4	2	10	--	6	54.1	0.5	2.6	34.3	2.1	1.8
400	10:1	0	10	12	0	--	11	0	0	0	0	0	0
400	50:1	12	13	14	10	--	8	28.0	3.7	28.3	1.6	1.5	6.1
400	100:1	16	13	13	12	--	8	42.0	3.6	35.3	4.8	0.9	6.7
400	0	9	3	10	9	--	8	27.6	1.2	27.8	5.0	0	4.7

*Total quality scores not observed in 1971.

The level of optimum sludge amendment relative to corn yield was as earlier indicated by the TQS 100 T/A in combination with nitrogen at C:N of 50:1. On the basis of two crop seasons, yearly amendments of no more than 100 T/A in combination with nitrogen would permit more or less continuous and concurrent use of farm land for sludge disposal and crop production.

Quality Test Scores of beans were not determined for the 1971 Yearly Amendment Design because of the marked sensitivity of beans to the first of the three amendments. Bean yields in 1971 following the second addition of sludge at 100 T/A were from 60 to 80 percent less than yields from these plots in 1970. Bean yields from incorporation of sludge under the Tolerance design at 200 T/A as a single amendment without nitrogen in the fall of 1969 were essentially identical in 1970 and 1971. Split application of sludge at the 200 T/A rate, with half portions applied in 1969 and 1970, however, resulted in a many-fold reduction in the 1971 yield.

The toxic factors of sludge are more apparent and yield reductions of corn and beans are greater when sludge incorporation into soil is by Yearly Amendment than by Tolerance design.

Plot Quality Evaluation--1972

Total quality scores of corn in 1972 plot evaluation were lower than those of controls at both the 100 and 200 T/A amendment levels with the exception of the sludge-nitrogen combination of 100 T/A--10:1 C:N. No consideration relative to original experimental design should be given the 400 T/A amendment of the Yearly Amendment approach as the third aliquot of sludge could not physically be worked into test plots.

Corn yields resulting from yearly amendments of 100 T/A at C:N of 10:1 increased over 3 years from 10.3 to 37.8 lbs per subplot. At the same sludge level but with lower nitrogen fertilization level of 50:1 C:N, yield was evenly distributed over a 3 year period. Extreme reductions in yield resulted from yearly amendments of 200 T/A however. The third successive amendment at the 400 T/A rate could not be physically incorporated into plots and as a consequence was eliminated from study. In view of the reduced yield in the 1972 crop on the 400 T/A plots, it appears reasonable to assume adverse effects equal to or greater than those obtained with the third incorporation of 200 T/A.

The 100 T/A sludge amendment applied to soil with nitrogen at C:N of 50:1 and 100:1 for 3 successive years produced bean plants of better quality than those of controls. The TQS obtained for plants on sludge amended plots of 14 and 12 for the low and high C:N respectively and those of 6 and 10 for comparable controls show the moderately superior condition of beans on the sludge amended plots.

No major differences in yields were observed between the 1971 and 1972 bean crops grown at all nitrogen levels on the 100 T/A Yearly Amendment plots. The maximum yield in 1972 from the 100 T/A plots however was 40 percent less than that from the control plots. Reductions in yield of up to 90 percent or so resulted from successive yearly incorporation of 200 T/A rates.

DISPOSAL DESIGN

Plot Quality Evaluation--1972

Growth of corn and beans on the Disposal plots paralleled that of the test crops on the Yearly Amendment plots. The TQS shown in Table 30 indicates that optimum growth under both objectives occurred at the 100 T/A level with the nitrogen addition most favorable in the Disposal approach at C:N ranging from 50:1 to 100:1 and in Yearly Amendment, from 10:1 to 50:1.

Corn yields as depicted in Tables 31 and 32 were significantly greater with 100 T/A amendments from the Yearly Amendment than from the Disposal plots. In contrast, no differences occurred in bean production from 100 T/A plots amended under the two objectives, but yields were well under those from control plots.

TABLE 30

TOTAL QUALITY SCORES OF 1972 CORN AND BEAN CROPS ON DISPOSAL DESIGN PLOTS

Sludge T/A	Nitrogen Addition lbs	Total Quality Scores Plot No.	Corn	Plot No.	Beans
0	45.8	17A	0	21A	1
0	9.2	17B	8	21B	4
0	4.6	17C	12	21C	10
0	0	17D	17	21D	15
	C:N Ratio				
100	10:1	18A	8	22A	4
100	50:1	18B	11	22B	7
100	100:1	18C	6	22C	10
100	0	18D	5	22D	6
200	10:1	19A	4	23A	5
200	50:1	19B	6	23B	6
200	100:1	19C	6	23C	6
200	0	19D	6	23D	7
400	10:1	20A	12	24A	9
400	50:1	20B	11	24B	7
400	100:1	20C	12	24C	8
400	0	20D	7	24D	6

TABLE 31

EFFECT OF CLARIFIER SLUDGE ON CORN AND BEAN YIELD IN FIELD PLOT DISPOSAL STUDIES

Sludge Tons/A	Nitrogen Addition Lbs-N	Plot No.	Lbs Corn	Plot No.	Lbs Beans
0	45.8	17A	1.0	21A	0
0	9.2	17B	5.0	21B	1.5
0	4.6	17C	21.0	21C	5.3
0	0	17D	40.7	21D	23.2
	C:N				
100	10:1	18A	20.7	22A	1.6
100	50:1	18B	26.7	22B	10.4
100	100:1	18C	21.6	22C	19.2
100	0	18D	10.8	22D	5.8
200	10:1	19A	22.8	23A	0.8
200	50:1	19B	6.2	23B	1.7
200	100:1	19C	6.2	23C	5.7
200	0	19D	7.3	23D	0.9
400	10:1	20A	26.5	24A	7.3
400	50:1	20B	20.9	24B	3.3
400	100:1	20C	12.5	24C	3.5
400	0	20D	14.3	24D	4.6

TABLE 32

STATISTICAL RANKING ACCORDING TO DUNCAN'S NEW MULTIPLE RANGE TEST FOR CORN AND BEAN YIELD--DISPOSAL DESIGN FOR 1970, 1971, 1972

Plot No.	Sludge Tons/A	Nitrogen Addition	Corn Yield Lbs	Plot No.	Sludge Tons/A	Nitrogen Addition	Bean Yield Lbs
17A	0	45.8#	1.0	21A	0	45.8	0.0
17B	0	9.2#	5.0	23A	200	10:1	0.8
19B	200	50:1	6.2	23D	200	0	0.9
19C	200	100:1	6.2	21B	0	9.2	1.5
19D	200	0	7.3	22A	100	10:1	1.6
18D	100	0	10.8	23B	200	50:1	1.7
20C	400	100:1	12.5	24B	400	50:1	3.3
20D	400	0	14.3	24C	400	100:1	3.5
18A	100	10:1	20.7	24D	400	0	4.6
20B	400	50:1	20.9	21C	0	4.6	5.3
17C	0	4.6#	21.0	23C	200	100:1	5.7
18C	100	100:1	21.6	22D	100	0	5.8
19A	200	10:1	22.8	24A	400	10:1	7.3
20A	400	10:1	26.5	22B	100	50:1	10.4
18B	100	50:1	26.7	22C	100	100:1	19.2
17D	0	0	40.7	21D	0	0	23.2

Any two values not bracketed by same line are significantly different; any two values bracketed are not significantly different at 5% level.

CHARACTERISTICS OF SLUDGE AMENDED SOILS

The initial incorporation of sludge into field plots at the 100, 200 and 400 T/A rates produced an immediate improvement in soil tilth. The 600 T/A amendment however was so voluminous that even with batch wise rotovation of the total amount in 3 or 4 separate portions the top 6 inches or so of the plot was not satisfactorily mixed with the deeper portions. Improved tilth at all amendment rates, including the 600 T/A was noted during the 1970 spring plot rotovation and preparation for seeding.

Large pancake-like fungal growths occurred on the surface of sludge amended plots from early spring in 1970 and 1971 through both crop seasons. Observations in April and August of 1972 as shown in Table 33 established a positive correlation between the presence of fungi and the yearly addition of sludge.

Sludge incorporation in the fall of 1970 and 1971 to Yearly Amendment and Disposal plots became increasingly more difficult with each amendment. Formation of sludge-clay aggregates of fist size and larger throughout plots produced isolated islands of sludge in various stages of decomposition. Incomplete mixing of the third sludge addition with soil and partially composted amendment of previous years was wide-spread during the third and final year of sludge addition.

Following crop harvest in 1972, soil samples were obtained from all plots for ash and volatile solids analysis. Sample cores collected from five random areas within each sub-plot were combined, mixed and a 500 g portion air dried and stored for later analysis.

Volatile solids levels as shown in Table 34 in the fall of 1972 of all soils amended with sludge between 1969 and 1972 were greater than those of unamended control soils. The increase in volatile or organic components of soil was proportional to the quantity and frequency of sludge addition. A total of 600 T/A applied in yearly amendments of 200 T/A increased residual organic content in 1972 by 190 to 220 percent, while application in 1969 of the entire 600 T/A in the Tolerance design increased the organic fraction in 1972 by only 80 to 90 percent. Undegraded and

TABLE 33

EFFECT OF 8 AND 30 MONTHS RESIDENCE OF SLUDGE AMENDMENTS ON OCCURRENCE OF SURFACE FUNGAL GROWTHS

Disposal Design	Sludge T/A	Nitrogen C:N	Fungal Growths (Avg. No./ Replicate)
Yearly Amendment 8 Mo. Residence	100	10:1	12
		50:1	11
		100:1	12
		0	12
	200	10:1	12
		50:1	11
		100:1	9
		0	3
	400	10:1	6
		50:1	13
		100:1	9
		0	9
Disposal 8 Mo. Residence	100	10:1	9
		50:1	8
		100:1	16
		0	12
	200	10:1	11
		50:1	13
		100:1	15
		0	5
	400	10:1	7
		50:1	12
		100:1	8
		0	10
Tolerance 30 Mo. Residence	200	All Levels	None
	400	All Levels	None
	600	All Levels	None
Controls	None	All Levels	None

TABLE 34

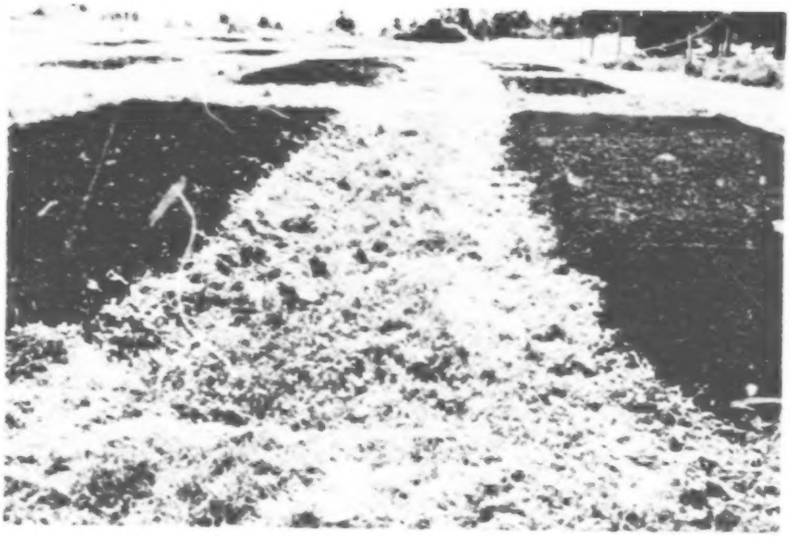
ASH AND VOLATILE SOLIDS CONTENT OF SLUDGE AMENDED SOILS

Sludge T/A	Disposal Design	Nitrogen lbs	Plot No.	Percent Ash	Percent Volatile Solids	Increase In Volatile Solids, Percent
0	Control	91.6	1A	90	10	--
0	Control	18.3	1B	90	10	--
0	Control	9.2	1C	90	10	--
0	Control	0	1D	90	10	--
		C:N				
100	Y.A.*	10:1	10A	84	16	60
100	Y.A.	50:1	10B	81	19	90
100	Y.A.	100:1	10C	82	18	80
100	Y.A.	0	10D	85	15	50
200	Y.A.	10:1	11A	68	32	220
200	Y.A.	50:1	11B	68	32	220
200	Y.A.	100:1	11C	69	31	210
200	Y.A.	0	11D	71	29	190
200	T*	10:1	2A	87	13	30
200	T	50:1	2B	87	13	30
200	T	100:1	2C	87	13	30
200	T	0	2D	87	13	30
400	T	10:1	3A	85	15	50
400	T	50:1	3B	84	16	60
400	T	100:1	3C	85	15	50
400	T	0	3D	85	15	50
600	T	10:1	4A	81	19	90
600	T	50:1	4B	81	19	90
600	T	100:1	4C	81	19	90
600	T	0	4D	82	18	80

*Y.A. - Yearly Amendment; T - Tolerance Design.

partially degraded components of the 3 yearly amendments of 200 T/A are the dominant factors in the accounting for the 6-8 inch greater elevation of the Yearly Amendment over the 600 T/A Tolerance plots. The photograph in Figure 15 shows the difference in plot volume when sludge was added at a rate of 200 T/A each of 3 years or 600 T/A in the first year.

Corn crops within 2-3 weeks of harvest on the 400 and 600 T/A Tolerance plots were free from symptoms of water stress during a 2 week hot spell in late August 1972, while the corn on all other amended and unamended plots showed marked wilting from water deficiency. As shown in Figure 16 the temporary wilting was most evident immediately prior to irrigation. Frequency of irrigation minimized adverse effects of water stress on yield, but under general field conditions amendments such as sludge that prevent such stress could be of agricultural importance.

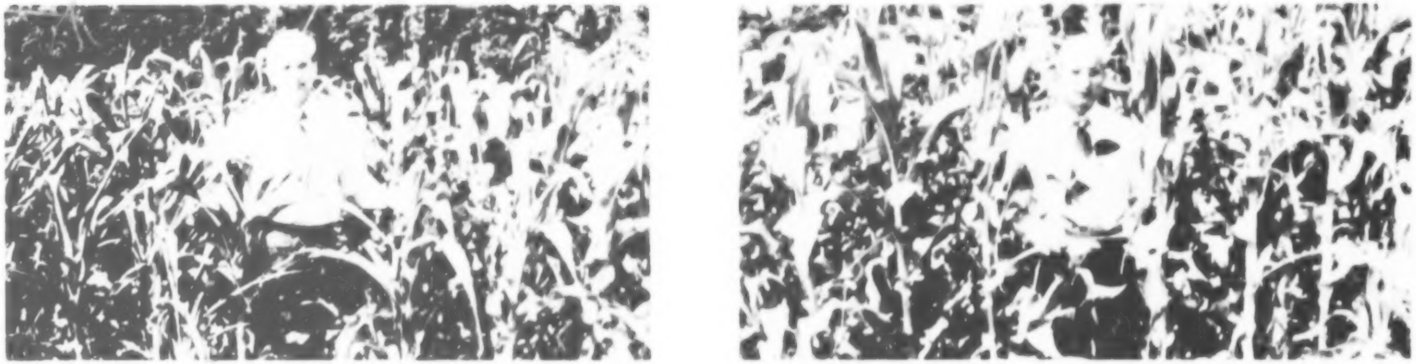


Plot on left received 600 T/A in Fall of 1969.
Plot on right received 200 T/A/yr for 3 years.

FIGURE 15. COMPARISON OF TWO PLOTS RECEIVING TOTAL OF 600 T/A SLUDGE.

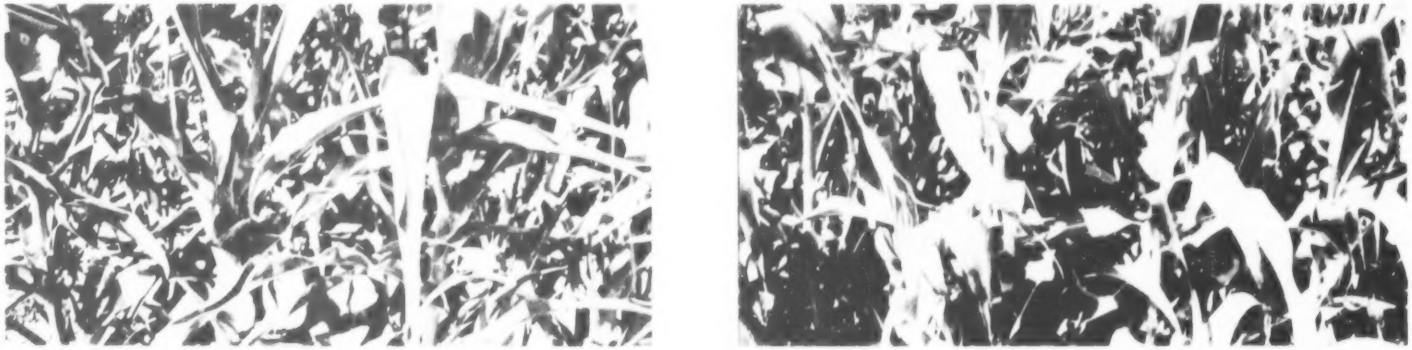
A.
"0" Tons/Acre Sludge

B.
400 Tons/Acre Sludge



No Nitrogen 9.2# Nitrogen

No Nitrogen 9.2# Nitrogen



Closeup of Left Subplot in "A"

Closeup of Left Subplot in "B"

FIGURE 16. EFFECT OF SLUDGE ADDITION ON WILTING OF CORN.

SECTION XI

MULCHING

ROAD CUT HYDROMULCH

Disposal of paper mill sludge as a hydromulch material offers a substantial volume outlet. The major use is in formulation of a grass planting slurry which is sprayed on highway cuts. The mulch provides the medium for holding seeds until they germinate. It also holds moisture and fertilizer so that after the application, no further attention is necessary. The mulch will slowly decompose, adding humus to the soil.

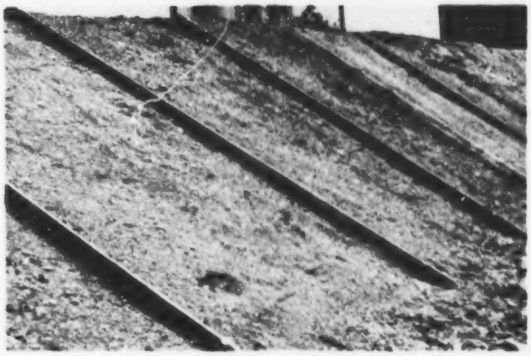
To simulate a highway-cut embankment, a 30° angle hillside slope was levelled and covered with 3-4 inches of top soil. As shown in Figure 17 the slope was divided into 5 plots each 5 ft wide by 14 ft long. Type of equipment used and method of application are also shown. Amounts of grass seed and fertilizer used for each of the 3 plantings are shown in Table 35.

TABLE 35

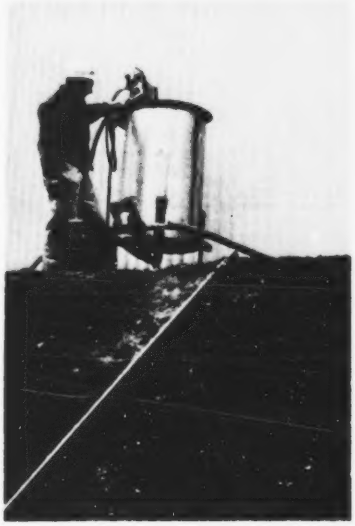
APPLICATIONS ON HYDROMULCH PLOTS

Application Date	4/13/71	9/24/71	4/26/72
Lb Grass Seed/Acre*	260	390	390
Type Fertilizer, % (N-P-K)	5-10-50	23-19-17	23-19-17
Lb Fertilizer/Acre	1270	415	415

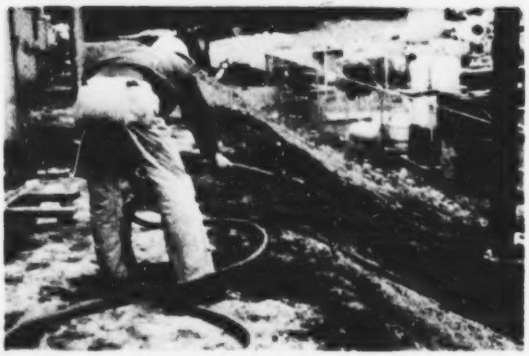
*Highway grass seed mix of 50% English rye and 50% creeping fesque.



5' x 14' Hydromulch Plots



Hydromulch Mix
Tank, Mixer, Pump



Application of Hydromulch

FIGURE 17. HYDROMULCH APPLICATION ON SIMULATED HIGHWAY ROAD CUT.

Each grass seed-fertilizer combination which was slurried for hydromulching was mixed in a 100 gallon feed tank. Slurrying was accomplished with an air motor-driven portable mixer. Slurries were pumped from the tank by a gasoline-driven portable pump and sprayed on each plot.

Giving each application a weighted rating, i.e., its average, it appears that almost any formulation except 3000 and 6000 lb/acre of sludge would equal or excel the wood fiber product. From Table 36, this would include mixtures rated 3 or lower. The choice of hydromulch product then depends on comparative prices of the material. The cost without profit of a delivered bale of semi-dried sludge in a local area is about $20/dry ton. Pressed sludge, delivered in bulk, would be $14-17/dry ton. With a reasonable addition of profit and selling cost to the above, the product should be competitive to materials now being used.

Because the basic operation of hydromulching is spraying on material as a slurry, an important objective is to apply at high solids content, or consistency. Generally, paper mill sludges have a low enough freeness, or drainage rate, to stay well mixed in water. The data of Table 36 show that in all cases, sludge and sludge-bark mixtures can be applied at higher consistencies than the wood fiber hydromulch.

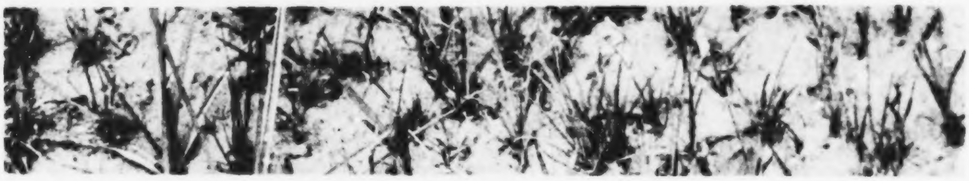
Variable amounts of sludge and sludge-bark mixtures were compared to a control wood fiber hydromulch. Plots were not watered during the growing period of 60 to 90 days. At the end of the growth period each plot was visually rated for growth and coverage.

Differences can be noted in the photographs shown in Figure 18 taken of one planting series; however the final evaluations were based on overall plot growth. These ratings for each series are shown in Table 36.

TABLE 36

HYDROMULCH APPLICATION AND EFFICACY RATING

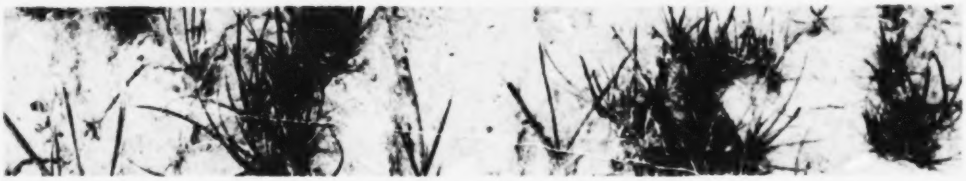
Plot Rating	Lb Wood Fiber/Acre	Lb Sludge /Acre		Lb Bark Dust/Acre	Application Consistency, %
		4/13/71			
1	--	1000	+	1000	1.96
2	2000	--		--	1.41
3	--	2000		--	1.96
4	--	1500	+	1500	2.27
5	--	3000		--	2.27
		9/24/71			
1	--	4000		--	2.90
2	--	2000	+	2000	2.90
3	--	1500	+	1500	2.15
4	--	3000		--	2.50
5	2000	--		--	1.10
		4/26/72			
1	--	3000	+	3000	3.04
2	--	4000		--	2.44
3	2000	--		--	0.98
4	--	6000		--	2.41
5	--	2000	+	2000	2.44



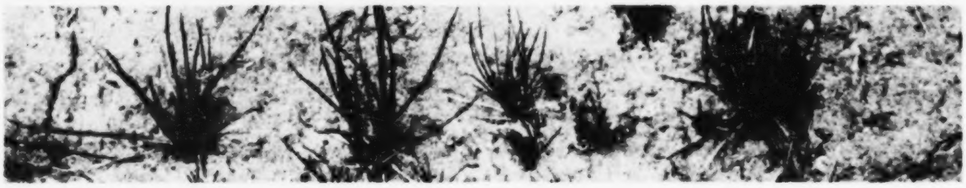
50% Sludge-50% Bark, 2000#1Acre

Wood-Fiber Hydromulch, 2000#1Acre

100% Sludge, 2000#1Acre



50% Sludge-50% Bark, 3000#1Acre



100% Sludge, 3000#1Acre

FIGURE 18. GRASS GROWTH-HYDROMULCH PLOTS 4/13/71.

CROP MULCHING

Hydromulching

Evaluation of mulching potential of sludge was made with raspberry, strawberry, and tomato test crops grown in 10 x 38 ft plots. Plot design is shown in Figure 19. Four plots of a single row of Willamette variety of red raspberry transplants were established with 4 foot spacing between plants. Four plots of Northwest variety strawberry plants were set in 3 rows per plot with spacing of 3½ feet between rows and 1½ feet between plants. The Earlianne tomato test crop was not planted until after sludge application. Three plots of tomatoes on 3½ foot centers were set into soil by removing an approximate 4 inch diameter disc of the sludge blanket for each transplant.

Sludge was applied as a slurry or hydromulch for the hydromulch study. In order to facilitate application, an approximate 1.3% slurry of sludge was maintained in suspension by constant stirring and sprayed on surface of plots through a specially designed nozzle. Plants established in plots prior to hydromulching were covered to keep foliage free of sludge.

One of the four prepared plots of raspberry was used in a special treatment not related to mulching study. This single plot was amended with sludge at a 200 T/A rate and nitrogen to give a C:N ratio of 100:1 prior to planting of test plants.

Effectiveness of the sludge hydromulch in weed control was measured by weight of weeds harvested and time interval required to remove weeds. Both weed yield and removal intervals decreased with increased thickness of mulch.

The hydromulch layer was ineffective in control of such weed species as Canadian thistle and Quack grass.

Tomato Yield

Tomatoes were picked through the growing season as they ripened. Final harvest was made the day following the first killing frost. Total number and weight of harvested fruit along with percentage by weight and number exhibiting soft spots are given in Table 37.

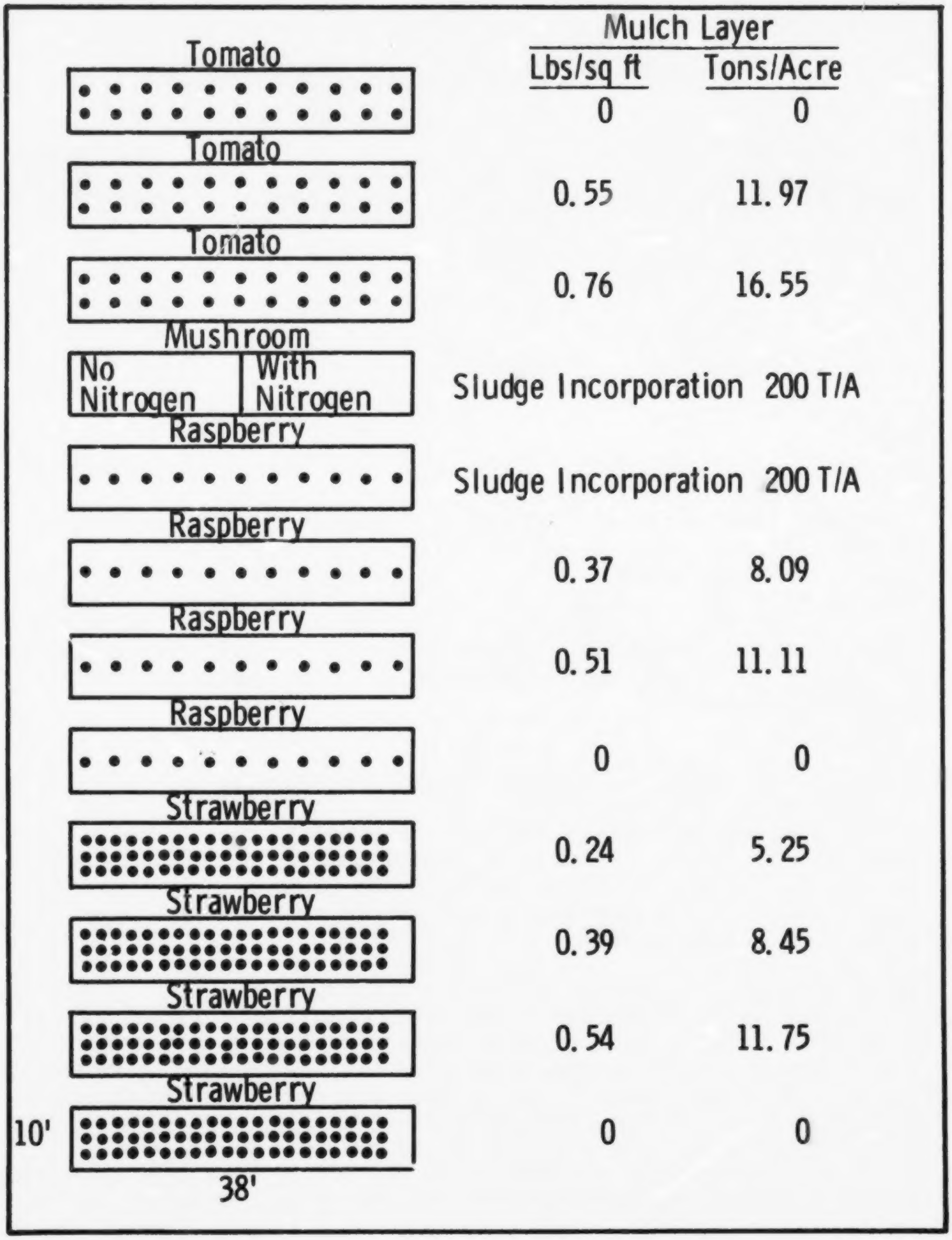

Mulch Layer
Lbs/sq ft
Tons/Acre
Tomato
0
0
Tomato
0.55
11.97
Tomato
0.76
16.55
Mushroom
No Nitrogen
With Nitrogen
Sludge Incorporation 200 T/A
Raspberry
Sludge Incorporation 200 T/A
Raspberry
0.37
8.09
Raspberry
0.51
11.11
Raspberry
0
0
Strawberry
0.24
5.25
Strawberry
0.39
8.45
Strawberry
0.54
11.75
Strawberry
0
0
10'
38'

FIGURE 19. DESIGN SHOWING HYDROMULCH PLOTS.

TABLE 37

EFFECT OF HYDROMULCH ON TOMATO YIELD

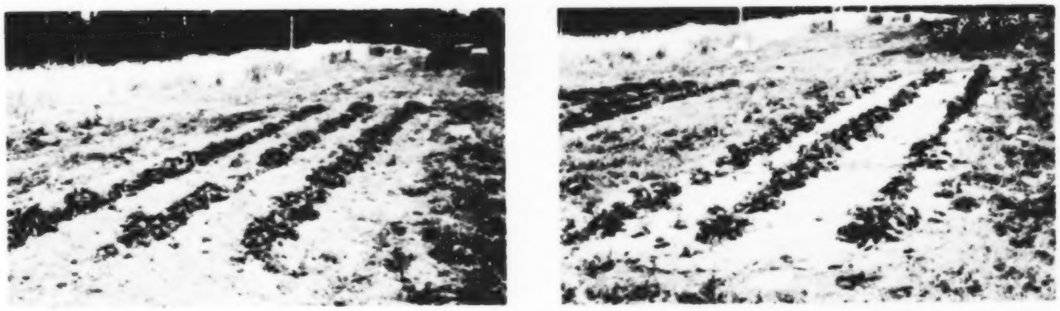
Hydromulch Addition Tons/A	Hydromulch Addition Lbs/sq ft	Total Lbs/Plot	Total Number/Plot	Percentage Soft Tomatoes By Wt	Percentage Soft Tomatoes By No.
Control--No Mulch		343	1226	8.4	7.8
12	0.55	250	773	3.9	4.1
17	0.76	247	786	2.7	3.6

Tomatoes transplanted through a mulch layer equivalent to 12 and 17 tons/acre resulted in poor growth and reduced yields. Light green color of foliage developed early in season with plants grown on mulched plots, indicating an adverse effect. Sludge layer did however provide a barrier between fruit and soil. Fruit resting on soil had a higher incidence of "soft spot" than tomatoes resting on the hydromulch sheet.

Raspberry and Strawberry Yields

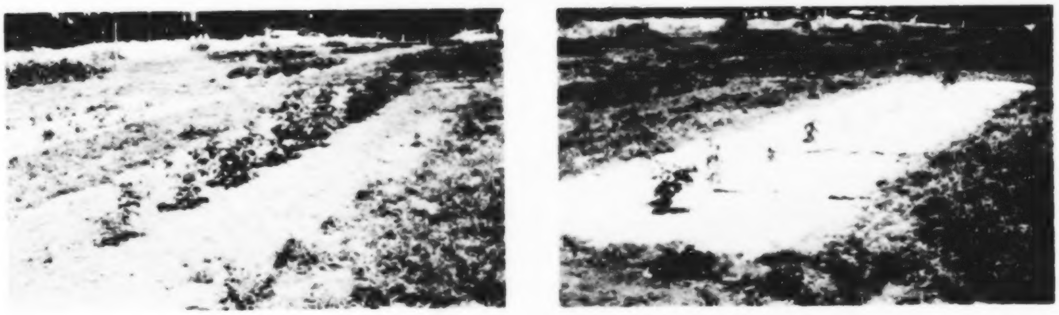
In 1970 excessive weeds plagued control plots. Their removal disturbed strawberry plant growth which subsequently resulted in 1971 yield decrease. There were considerably less weeds on treated plots and their removal had less impact on plant growth.

Results shown in Table 38 show a very low strawberry yield in control plot compared with yields normally obtained in that area. Data do indicate, however, that hydromulching, even though effective in weed control, decreased strawberry yield. When hydromulch layer was increased in thickness from 5.3 to 11.8 T/A, yields decreased from 171.3 to 87.9 lbs. These data are similar to those in the raspberry plots. Photographs in Figure 20 depict hydromulch appearance and its effect on strawberry, raspberry and tomato plants.



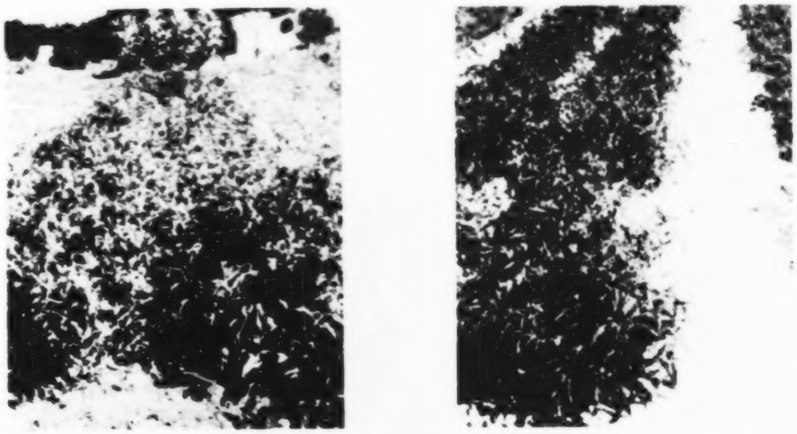
Strawberry - Control

0. 54 lbs/sq ft



Raspberry - Control

0. 51 lbs/sq ft



Tomato - Control

0. 76 lbs/sq ft

FIGURE 20. EFFECT OF HYDROMULCH LAYER ON TEST CROPS.

TABLE 38

RASPBERRY AND STRAWBERRY YIELDS ON HYDROMULCHED PLOTS

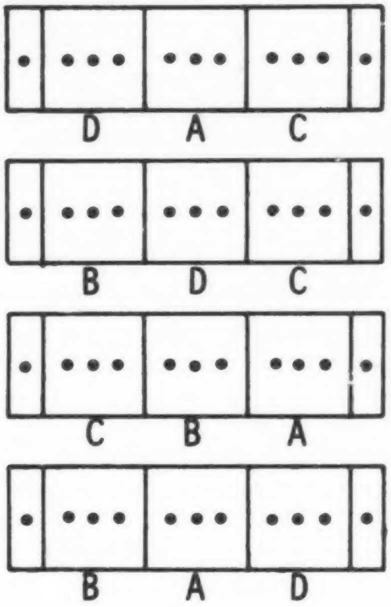
Crop	Sludge Addition Tons/Acre	Sludge Addition Lbs/sq ft	Pounds--Total Yield
Strawberry	0	0	45.8
Strawberry	5.3	0.24	171.3
Strawberry	8.5	0.39	99.1
Strawberry	11.8	0.50	87.9
Raspberry	0	0	38.6
Raspberry	8.1	0.37	12.5
Raspberry	11.1	0.51	25.6

Bulk Mulching

After 1970 and 1971 harvest data were collected, the strawberry and raspberry plants were thinned to uniformity. The revised experimental scheme, shown in Figure 21 was designed to obtain greater replication, evaluate mulching rather than hydromulching and to determine effect of varying sludge depth.

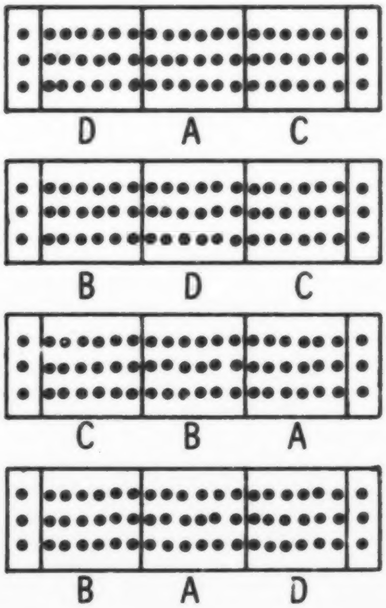
After 1971 harvest each plot was divided into 10' x 10' subplots leaving 4 feet of guard plants on each end. Subplots were divided with 2" x 10" planks. Raspberry plants grown on sludge incorporated plots were also used in the design.

Sludge having a wet density of 42.3 lbs/cu ft or 10.6 lbs/cu ft (dry basis) was placed in the enclosures to measured depths varying from 1.5 to 6 inches.


D A C
B D C
C B A
B A D

Raspberry Plots

Subplot	Mulch Layer Thickness (Inches)	Tons Per Acre
A	0	0
B	2	38.4
C	4	76.8
D	6	115.2


D A C
B D C
C B A
B A D

Strawberry Plots

Subplot	Mulch Layer Thickness (Inches)	Tons Per Acre
A	0	0
B	1.5	28.7
C	3.0	57.4
D	5.0	95.9

FIGURE 21. RANDOMIZED PLOT DESIGN FOR BULK MULCHING EXPERIMENT.

Analysis of data summarized in Table 39 and shown in more detail in Tables XI and XII, in Appendix, indicate a significant difference in yields obtained with treatments on strawberry plots. However no significance could be obtained with sludge addition on raspberry plots.

TABLE 39

SUMMARY OF STRAWBERRY AND RASPBERRY YIELD DATA UNDER BULK MULCH CONDITIONS

Crop	Sludge Addition		Total Ounces Per 3 Plots (10' x 10')
	Tons/Acre	Inches Thick	
Strawberry	0	0	1761 *
Strawberry	28.7	1.5	1689
Strawberry	57.4	3.0	1434
Strawberry	95.9	5.0	1203
Raspberry	0	0	555
Raspberry	38.4	2.0	564
Raspberry	76.8	4.0	728
Raspberry	115.2	6.0	839

*Any two values bracketed by same line are not significantly different at 5% level.

Pictures in Figures 22 and 23 show sludge application in enclosures and randomization of subplots.

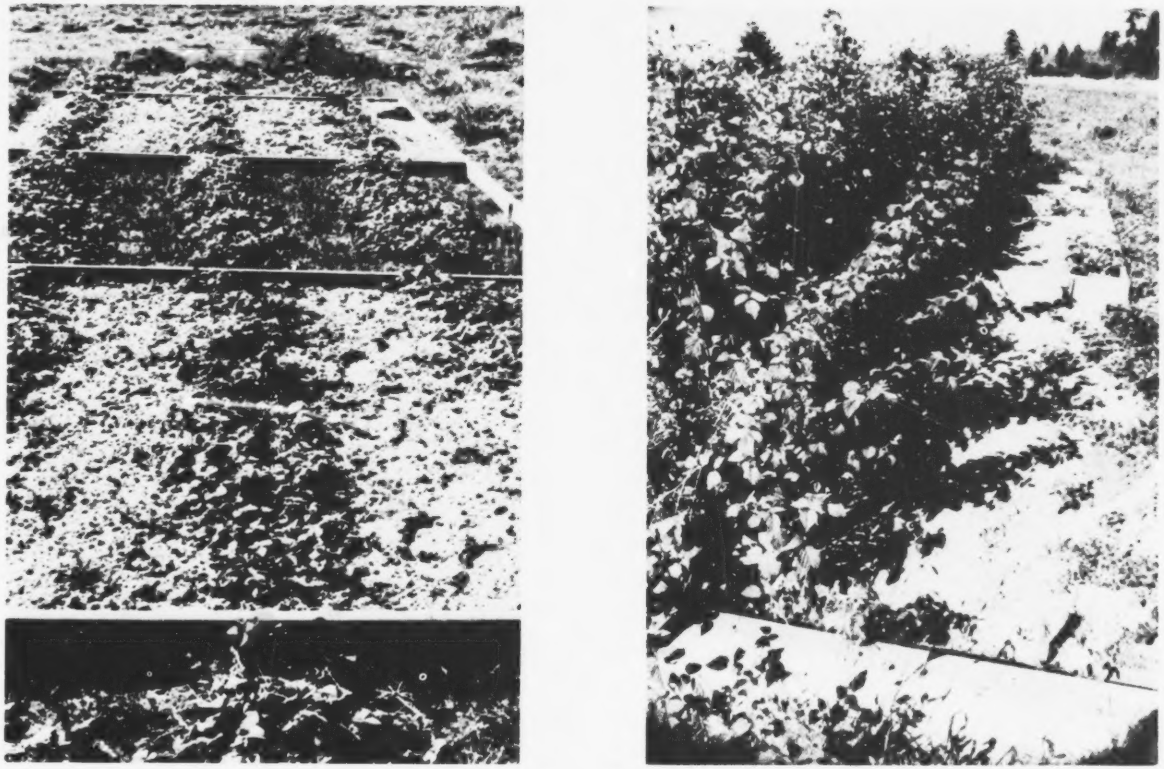


FIGURE 22. STRAWBERRY AND RASPBERRY PLOTS SHOWING ENCLOSURES AND SLUDGE DEPTHS.

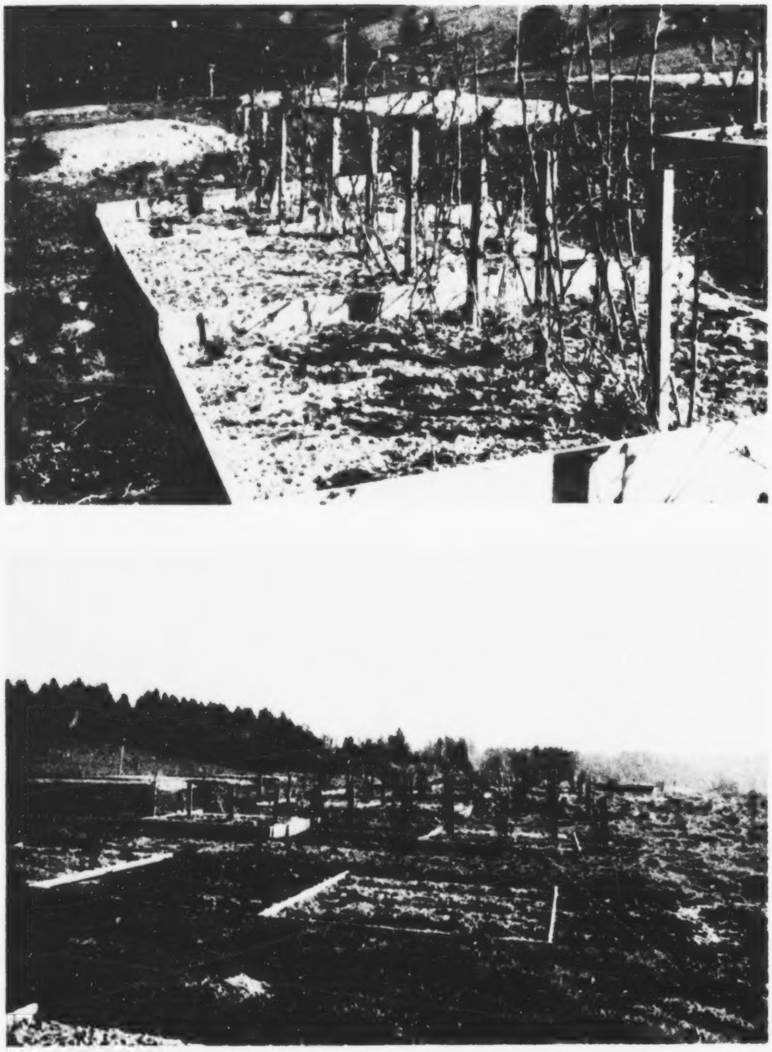


FIGURE 23. STRAWBERRY AND RASPBERRY PLOTS SHOWING ENCLOSURES AND SLUDGE DEPTHS.

SECTION XII

MISCELLANEOUS USES

MUSHROOM CULTURE

Dense mats of mycelia composed of separate brown and white strands were observed during the spring of 1970 in plots where sludge was incorporated into soil the previous fall. Two species of fungi are associated with these colored mycelia. The brown color characterizes the dominant growth of the *Morchella* species or the "morel", and the white mycelium that of the *Oedodendron* species. These two fungi are invariably found in mixed mycelial association. Growth of *Morchella* sp. appears to be dependent upon association with *Oedodendron* (5).

The observed mycelium was very productive of morel sporophores. Sludge amendments favored growth of morels of excellent quality and large size (Figure 24).

The unexpected and large numbers of morels collected from sludge amended plots were indicative of a possible key role for clarifier sludge as a component of a morel culture medium. Commercial mushroom interests have long sought a successful morel culture medium. However the physical or chemical factors required to shift the mycelium to fructification or morel development have not been found.

To test the effect of sludge amendments on morel production a special test plot was established. Sludge at 200 T/A was rototilled into a 10 by 38 foot plot. The sludge amended plot was inoculated with a heavy suspension of mycelial fragments and spores prepared from morels collected earlier. Ammonium nitrate was added to $\frac{1}{2}$ of the plot to give a C:N of 100:1. Reduced light intensity and increased humidity of plot was produced by constructing a box-like cover which fitted 20 inches above the bed with sides extending downward to within 6 inches of the soil surface.

Morels continued to appear during the springs of 1971 and 1972. Production of morel was almost without exception associated with sludge amended plots. The mushrooms developing in the grassy walkways between beds were consistently located on the downhill drainage or runoff side of sludge supplemented plots. However, no morels occurred on the special plot with the box cover during either spring of 1971 or 1972.

A. Morels Growing on Sludge Amended Plot

B. Morel Harvest Showing Size.

FIGURE 24. MOREL MUSHROOMS FOUND GROWING ON SLUDGE PLOTS.

Some limited studies were conducted by Dr. C. Fordyce (5) of the U. S. Department of Agriculture at Beltsville, Maryland, who became interested in morel growth on the experimental plots. His work showed Morchella grew well with abundant sclerotia formation when ammonium nitrate and yeast extract were added to sludge. His studies also indicated differences in utilization of sludge by different strains of Morchella. Use of sludge as casing medium for Agaricus campestris, the mushroom of commerce, was not satisfactory as A. campestris could not penetrate the sludge layer. Contamination of sludge under mushroom house conditions by Trichoderma and Aspergillus species was observed by both the USDA and a commercial grower.

OIL ABSORBENCY

Clarifier fibers from two mills were evaluated by automobile garage operators for possible use as a garage floor absorbent sweeping compound. These materials absorbed oil well, but overall performance was rated below the products normally used such as rice hulls and sawdust. The major objection to rice hulls as a sweeping compound is the severe dust problem which exists with this material. Dried sludge, on the other hand, was judged good from a dust standpoint.

Garages pay 5 to 6 cents per pound for rice hulls and other sweeping compounds such as vermiculite. Dried, particulated clarifier fiber would probably cost less than 2 cents per pound in bags. Added to this would be selling expense and distribution cost.

This study shows that clarifier sludge would probably have to be sold at a lower price or be physically improved in order to compete with established sweeping compounds.

A possible suggested use for paper mill sludge has been as an oil absorbent for accidental oil spills on water. Laboratory work in evaluating oil absorbency indicates that on a dry basis, sludge can absorb about 1.2-1.7.times its weight. This is equivalent to a usage of one cu ft of sludge for 6 gallons oil spill. To convert sludge into a product having oil absorbing capabilities, it must be oil-treated and dried to facilitate handling and storage. The oil-treated product should also be baled. The estimated delivered cost of 1000-1400 lb bales to a destination of

250 miles is about $40/dry ton solids, allowing for a 3 year cash flow pay-out time. As an example, a 46,000 cu ft barge load would absorb 276,000 gallons of oil. This would be a reasonable amount for dockside leakage at a port location. Tanker spills at sea are usually much larger, and it would be impractical to use sludge for clean-up. Information in Table 40 compares sludge to other products for oil spills.

From data in Table 40, it can be concluded that on the basis of cost and storage volume, sludge is not a competitive material for oil spill clean-up.

CATTLE FEED

The following evaluations of sludge for silage and as a source of feed for ruminants were conducted at Louisiana State University (LSU) under the direction of Dr. Louis L. Rusoff, nutritionist, Department of Dairy Science. Source of sludge was from a southern mill which produces unbleached kraft pulp that is converted to various grades of coarse paper and linerboard. Sludge from primary treatment was centrifuged to a consistency of about 20%. This material was used for the studies described. Approximate analysis of the dry product showed that it contained the following:

	%
Crude Protein	2.0
Crude Fat	1.8
Crude Fiber	66.4
Lignin	12.7
Ash	17.1

Silage Feeding Studies

For the initial silage study additives such as Johnson grass, cottonseed meal, urea and ground corn were used in different combinations with the sludge in experimental silos. The silos were 55-gallon drums filled with compressed material. The ensiled material was stored in the silos for a period of 4 months. The combinations of additives and sludge are shown in Table 41.

TABLE 40

COMPARISON OF MATERIALS FOR OIL SPILL CLEAN-UP

Material	Volume Required, cu ft/million gal. oil	Dock-Side Cost, $/million gal. oil
Ground Pine Bark (Undried)	450,000	33,800
Ground Bark (Air Dry)	310,000	58,100
Sawdust (Air Dry)	330,000	61,900
Chemical Dispersant	2,670	95,000
Catalyst Powder	800	106,000
Sludge (Dried, Oiled)	167,000	113,000

TABLE 41

ENSILAGE MIXTURES FOR CATTLE FEED STUDIES

Silo No.	Dry Sludge	Johnson Grass	Cottonseed Meal	Urea	Molasses	Ground Corn	Whole Corn
1	50	50	-	-	-	--	--
2	50	45	5	-	-	--	--
3	50	45	-	-	5	--	--
4	50	44	-	1	5	--	--
5	50	--	-	-	-	50	--
6	50	--	-	1	-	49	--
7	50	--	-	1	-	--	49
8	100	--	-	-	-	--	--

The results obtained with the various combinations of additives and sludge which were ensiled are shown in Table 42. These results indicate that the pulp mill sludge is very difficult to break down compared to regular feed ensiling materials. Silage can be made from grass and corn after a 30-day storage period. The additives, Johnson grass and corn, formed silage, but the sludge remained unchanged during the four-month period. The best looking silage was No. 3 which contained 5% molasses and 45% Johnson grass and 50% sludge.

In checking the palatability of these ensiled mixtures, dairy steers consumed some of the first three mixtures (silos No. 1, 2 and 3), but did not relish it very much. The results indicate that sludge is not suitable for silage making. Modification or partial degredation of the cellulose material by acid or enzymes would probably result in improved fermentation, but this would be a costly process. Because of the low cost of cellulose-type feeds, it is economically unattractive to modify the sludge. For example, hay is presently selling for $14 to $20/ton in the Camas-Washougal area.

Sludge Feeding Studies

In addition to the silage studies, rations containing various amounts of sludge were fed to four groups of dairy steers (approximately 300 lb in weight) consisting of two animals per group. The sludge used in these trials was dried in a forced-air oven at 80° F. The dried material was then ground in a hammermill so that it could be mixed with the other ingredients in the grain ration. The composition and chemical analyses of the rations were as follows:

	Quantity in Pounds			
Ingredient	I	II	III	IV
Corn	72	67	62	57
Cottonseed Meal	20	20	20	20
Sludge	0	5	10	15
Molasses	5	5	5	5
Steamed Bonemeal	2	2	2	2
Salt	1	1	1	1

TABLE 42

SILAGE STUDY

Silo No.	Contents	After Ensiling (4 mos.)		
		Condition	Breakdown of Sludge	pH
1	50% freshly cut Johnson grass 50% paper by-product	Good Odor	None	5.2
2	5% cottonseed meal 45% Johnson grass 50% paper by-product	Brown Color & Poor Odor	None	5.0
3*	5% molasses 45% Johnson grass 50% paper by-product	Good Odor & Color	Slight	4.75
4	1% urea 5% molasses 44% Johnson grass 50% paper by-product	Ammonia Odor and Dark Color	Slight	8.8
5	50% ground corn 50% paper by-product	Poor Color Fair Odor	None	4.4
6	1% urea 49% ground corn 50% paper by-product	Poor Color and Odor (NH_3) Wet	None	8.7
7	1% urea 49% whole corn 50% paper by-product	Poor Color and Odor (NH_3)	None Corn Broken Down	8.6
8	100% paper by-product	Wet	None	7.45

*Best product.

The four groups of dairy steers were fed the rations for a 14-day period. No forage (hay, silage or pasture) was fed so that the palatability and the value of the rations could be checked.

The results of the cattle feeding studies are presented in Table 43. The results indicate that the dried sludge is not toxic to ruminants at levels up to 15% of the grain ration. However, it appears that the dried sludge has very low feeding value since the steers lost more weight as the percentage of sludge was increased in place of the corn.

TABLE 43

GRAIN CONSUMPTION AND WEIGHT GAINS OR LOSSES FOR DAIRY STEERS

Ration	Sludge, % of Ration	Daily Feed Consumption lbs	Daily Weight Gain or Loss, lbs
I Control	0	15	+ 0.5
II	5	14	- 1.0
III	10	13	- 1.3
IV	15	11	- 1.5

The addition of 15% sludge in the ration resulted in a weight loss of about 21 lbs in the two-week trial period. The animals receiving Ration IV were actually about 28 lbs lighter than the controls. Again, it appears that hydrolysis or modification of the cellulose is needed to make it nutritionally available to ruminants. The pulp mill cellulose sludge evidently is quite resistant to breakdown by the microbial population in the rumen.

CATTLE BEDDING

A small scale experiment was conducted to determine the practicability of using clarifier sludge as a bedding material for dairy cattle. Because of relatively heavy winter rains in the Camas area dairy cattle become extremely muddy if allowed to run in the fields. They are usually confined in corrals with concrete slabs and generally have access to a "loafing shed".

The dairy farm chosen for this evaluation had a "loafing shed" comprised of a row of box stalls on each side and a concrete runway through the center, extending the length of the shed. The box stalls are 7 feet long and 4 feet wide--sufficient room for a cow to lie down comfortably. A gravel base was used in the stalls to allow moisture to filter down.

At present dairy men preferably use wood shavings as bedding material in the box stalls. The shavings are thrown into the "head" end of the stall and gradually work their way out the back onto a concrete slab where, along with the manure, they are scraped up and hauled out to the fields. Shavings are an excellent bedding material. However, they are becoming increasingly scarce and expensive--having jumped in price from $4.00 to more than $5.00 per unit in the past year.

Three stalls were used in the experiment. About 11 lbs of sludge were used in each stall. This was good for four days, after which time an equal amount was again thrown into the head end of the stalls. After 4 days the third and final application was made.

Performance of the material as a bedding was judged as being satisfactory. It behaved in a similar fashion as shavings in respect to movement to the clean-out area. Sludge absorbed manure readily and as it became wet had a tendency to stick less to the cow. In order to determine sludge efficacy in keeping cows clean, a trial of considerable duration would be required.

It costs about 2½ cents per day per stall for shavings. Sludge would have to sell for less than $16.00 per ton delivered in order to compete with shavings.

GREENHOUSE APPLICATION

Sludge was evaluated as a potential component of synthetic potting media widely used in containerized agriculture. The containerized approach to production of ornamental species has essentially eliminated the practice of adding new soil to root area of the enlarging plant at each of the several "repottings". The current nursery method involves initial transplanting or seeding in a container sufficiently large to accommodate plant size at market stage. Potting medium requirements under these conditions of continuous and long time use are different from those of conventional or short time use. Synthetic soils should then be equivalent to or better than typical soil mixtures used for such purposes. These synthetic soils should exhibit characteristics such as: be light in texture; have low silt-clay content; have high water holding capacity; be resistent to compaction; have an attractive appearance; and present an environment unfavorable to plant pathogens.

A fertilizer mixture containing urea 4 lbs, superphosphate 4 lbs, sulfate of potash 2 lbs and limestone 2 lbs was incorporated into a cubic yard of soil. Standard greenhouse potting soil employed in studies was a volume based mixture of river loam-sand-peat moss at a ratio of 7:2:5. Potting media were wetted in excess and held overnight in the greenhouse.

Standard vegetable and ornamental crop varieties were planted into test media as seeds or transplants. Test plants originating as rooted cuttings were transplanted and maintained in greenhouse potting mixture for about one month prior to use. The root ball of the cuttings were freed of easily removed soil prior to transfer.

Standard potting soil, sand, peat moss, perlite, vermiculite, clarifier sludge and bark dust were evaluated alone or in various combinations as potting media.

Tests involving root knot nematode employed a standardized method in which tomato transplants served as the host plant. Heavily infested root knot soil maintained by continuous cropping with tomato was used to prepare nematode infested test soils. One volume soil inoculum was thoroughly mixed with 3 volumes of standard potting soil. Sludge was mixed with inoculated soil at 50, 100, and 200 T/A rates. Two

Bonney Best tomato seedlings 4 to 5 cm tall were transplanted in 2 inch plastic pots with sludge amended soils and control soils, and were grown in the greenhouse for 4 to 6 weeks.

Rating of root knot, following removal of soil from around plant roots, was made by evaluating relative gall size and number of galls on roots.

As shown in Table 44 two synthetic potting mixtures, using either vermiculite or perlite with sludge, were satisfactory growth media for containerized production of azalea, rose and zinnia. Greater size increases and superior appearance of Douglas fir seedlings, however, were obtained with all three component mixtures of sludge-bark-sand. The sludge-vermiculite mixture in all combinations tested were effective for tomato growth. Addition of sand as a component produced tomato plants that were superior to all other mixes.

Synthetic soil mixes with sludge as a component did not add noticeably to the gross weight of synthetic media, plant and container. The light weight characteristic of synthetic soils is of considerable importance in growth medium selection. Some nurserymen have abandoned standard potting mixtures because of weight.

Limited studies were made on the availability of water for plant growth in synthetic soils containing sludge and standard potting soil. Measurement of water holding capacity was made by observing the time interval between water application and incipient wilt. With zinnia test plants grown in sludge mixtures, wilting was delayed more than 8 hours beyond that of standard soil.

The 200 T/A sludge amendment of root knot nematode inoculated soil yielded tomato plants nearly free of root galls. Data shown in Table 45 indicate reducing sludge application from 200 T/A to 100 T/A and 50 T/A reduced disease control from 98% to 77% and 71% respectively. Varied organic amendments have been reported effective in nematode disease control and include chitin, straw, activated sludge and waste paper (6).

TABLE 44

COMPARISON OF PLANT GROWTH IN STANDARD SYNTHETIC AND SLUDGE-BASED POTTING MEDIA

Test Plant and Potting Media	Plant Growth Rating **(4)**
Azalae Plant(1)	
1. Standard Media	4
2. Sludge-Vermiculite	
1:1	2
1:2	3
2:1	4
3:1	2
3. Sludge Only	1
4. Vermiculite Only	1
Douglas Fir Seedlings(2)	
1. Standard Media	3
2. Sludge-Bark	
1:1	3
1:2	3
1:3	3
2:1	3
4:1	3
3. Sludge-Bark-Sand	
1:1:1	4
1:2:1	4
1:3:1	4
1:2:2	4
1:2:3	4
4. Sludge Only	2
5. Bark Only	3
6. Sand Only	3

Test Plant and Potting Media	Plant Growth Rating **(4)**
Tomato Plant(3)	
1. Standard Media	3
2. Sludge-Sand	
1:1	2
1:2	3
1:3	3
2:1	2
3:1	1
3. Sludge-Vermiculite	
1:1	3
1:2	3
1:3	3
2:1	3
3:1	3
4. Sludge-Perlite	
1:1	2
1:2	2
1:3	2
2:1	2
3:1	2
5. Sludge-Sand-Vermiculite	
1:1:1	4
6. Sludge-Sand-Perlite	
1:1:1	3
7. Sludge-Sand	
1:1	2
1:2	3
1:3	3
8. Sludge Only	1
9. Vermiculite Only	2
10. Perlite Only	2
11. Sand Only	2

(1) Azalae test duration - 8 weeks.

(2) Douglas fir test duration - 6 months.

(3) Tomato test duration - 7 weeks.

(4) Number 4 equals highest rating.

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TABLE 45

INFLUENCE OF SLUDGE ON CONTROL OF TOMATO ROOT KNOT NEMATODE

Sludge Addition (Tons/A)	Average Number of Galls	Percent Gall Reduction	Standard Deviation
0	91	--	26
50	26	71	17
100	21	77	7
200	5	98	5

Nematode control resulting from decomposition of organic soil amendments has been widely observed. Amendments in biological control have not provided sufficient control to satisfy farm requirements. Comparative control of sludge to other amendments is not known.

SECTION XIII

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Dr. B. C. Smale, Senior Research Biologist, Environmental Services Division
Dr. J. F. Cormack, Supervisor, Environmental Services Division
Mr. J. G. Coma, Supervisor, Central Research Division, Process Engineering
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Mr. R. Bafus, Technician
Mr. H. Husby, Technician
Mr. C. Esser, Technician

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SECTION XIV

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SECTION XV

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TABLE I

SLUDGE DECOMPOSITION AS MEASURED BY CARBON EVOLUTION WITH SOIL RESPIROMETERS. EXPERIMENT 1.

Sludge Addition (Tons/Acre)	Nitrogen Addition (C:N)	Milligrams Carbon Evolved							
		30 Days		60 Days		90 Days		120 Days	
		Sandy	Clay	Sandy	Clay	Sandy	Clay	Sandy	Clay
0	0	14	75	24	141	33	181	39	272
50	0	128	579	258	1111	369	1663	490	1958
100	0	155	781	361	1864	566	2550	653	3264
150	0	286	842	647	1966	996	2566	1414	3060
200	0	250	910	553	2459	854	3526	1115	4216
50	25:1	1115	1031	1721	1447	2017	1671	2176	1850
50	100:1	726	846	1044	1310	1238	1736	1414	1958
100	25:1	1496	1439	2228	2335	2752	2952	3210	3482
100	100:1	1142	1115	1467	1968	1785	2627	2040	3128
150	25:1	1578	1319	2879	2076	3740	2810	4352	3427
150	100:1	1179	967	1527	1630	1959	2305	2448	2815
200	25:1	1938	1408	3865	2039	4857	2625	5440	3074
200	100:1	1364	932	1810	1627	2320	2339	2856	2992
0	1*	9	86	23	151	47	200	204	245
0	2*	13	71	28	124	36	166	57	296
0	3*	17	65	22	129	29	189	150	277
0	4*	21	75	28	100	41	138	131	199

Same nitrogen amount used for: 1 50 T/A - 25:1, 2* 100 T/A - 25:1, 3* 150 T/A - 25:1, 4* 200 T/A - 25:1.

TABLE II

SLUDGE DECOMPOSITION MEASURED AS PERCENT EVOLVED WITH SOIL RESPIROMETERS. EXPERIMENT 1.

Sludge Addition (Tons/Acre)	Nitrogen Addition (C:N)	Percent Sludge Decomposed							
		30 Days		60 Days		90 Days		120 Days	
		Sandy	Clay	Sandy	Clay	Sandy	Clay	Sandy	Clay
50	0	3.6	16.5	7.4	31.7	10.5	47.4	14.0	55.8
100	0	2.1	11.1	5.1	26.6	8.1	36.3	9.3	46.5
150	0	2.7	8.0	6.1	18.7	9.5	24.4	13.4	29.1
200	0	1.8	6.5	3.9	17.5	6.1	25.1	7.9	30.0
50	25:1	31.8	29.4	49.0	41.2	57.5	47.6	62.0	52.7
50	100:1	20.7	24.1	29.7	37.3	35.3	49.5	40.3	55.8
100	25:1	21.3	20.4	31.7	33.3	39.2	42.0	45.7	49.6
100	100:1	16.5	15.9	20.9	28.0	25.4	37.4	29.1	44.6
150	25:1	15.0	12.5	27.3	19.7	35.5	26.7	41.3	32.5
150	100:1	11.2	9.2	14.5	15.5	18.6	21.9	23.2	26.7
200	25:1	13.8	10.0	27.5	14.5	34.6	18.7	38.7	21.9
200	100:1	9.7	6.7	12.9	11.6	16.5	16.7	20.3	21.3

TABLE III

SLUDGE DECOMPOSITION AS MEASURED BY CARBON EVOLUTION WITH SOIL RESPIROMETERS. EXPERIMENT 2.

Sludge Addition (Tons/Acre)	Nitrogen Addition (C:N)	Milligrams Carbon Evolved							
		30 Days		60 Days		90 Days		120 Days	
		Sandy	Clay	Sandy	Clay	Sandy	Clay	Sandy	Clay
0	0	21.1	29	22.9	81	23.5	175	25.3	219
100	0	78	663	209	1731	308	2413	519	3087
200	0	306	662	643	2410	886	3980	1328	5324
400	0	195	442	412	1280	530	2197	787	3770
600	0	187	187	305	344	409	694	671	1208
100	10:1	1162	1201	2159	2121	2782	2787	3213	3345
100	20:1	1036	1527	2095	2311	2535	2785	2988	3206
100	40:1	1090	1269	1755	2092	2035	2717	2399	3234
200	10:1	1402	1453	3134	3191	4374	4309	5404	5045
200	20:1	1716	1808	3498	3396	4635	4162	5778	4791
200	40:1	1234	1789	2121	2932	3084	4159	3678	4793
400	10:1	1143	2434	2312	4988	3324	5817	4331	6205
400	20:1	1276	2864	2888	4754	4416	5528	5732	6062
400	40:1	1040	2211	2889	3711	3622	4678	4099	5469
600	10:1	1150	2129	2120	3598	2997	4273	3678	4961
600	20:1	997	2024	2443	3092	3658	3673	4213	4190
600	40:1	941	728	2162	1481	3418	20	4448	2391

TABLE IV

SLUDGE DECOMPOSITION MEASURED AS PERCENT EVOLVED WITH SOIL RESPIROMETERS. EXPERIMENT 2.

Sludge Addition (Tons/Acre)	Nitrogen Addition (C:N)	Percent Sludge Decomposed							
		30 Days		60 Days		90 Days		120 Days	
		Sandy	Clay	Sandy	Clay	Sandy	Clay	Sandy	Clay
100	0	1.1	9.5	2.9	24.7	4.4	34.4	7.5	44.0
200	0	2.2	4.7	4.6	17.2	6.3	28.4	9.5	37.9
400	0	1.4	3.1	2.9	9.1	3.8	15.7	5.6	26.9
600	0	1.8	1.8	2.9	3.3	3.9	6.6	6.4	11.5
100	10:1	16.6	17.1	30.8	30.2	39.6	39.7	45.8	47.7
100	20:1	14.8	21.8	29.9	32.9	36.1	39.7	42.6	45.7
100	40:1	15.5	18.1	25.0	29.8	29.0	38.7	34.2	46.1
200	10:1	10.0	10.3	22.3	22.8	31.2	30.7	38.5	35.9
200	20:1	12.2	12.9	24.9	24.2	33.0	29.7	41.2	35.0
200	40:1	8.8	12.7	15.1	20.9	22.0	29.6	26.2	34.1
400	10:1	8.1	17.3	16.5	35.5	23.7	41.4	30.9	44.2
400	20:1	9.1	20.4	20.6	33.9	31.5	39.4	40.8	43.2
400	40:1	7.4	15.8	20.6	26.4	25.8	33.3	29.2	40.0
600	10:1	10.9	20.2	20.1	34.2	28.5	40.6	34.9	47.0
600	20:1	9.5	19.2	23.2	29.4	34.8	34.9	40.0	39.8
600	40:1	9.5	6.9	20.5	14.1	32.5	19.5	42.3	22.7

TABLE V

GREENHOUSE STUDIES TO DETERMINE EFFECT OF SLUDGE AND SUPPLEMENTAL NITROGEN ON SUNFLOWER GROWTH

Treatment No.	Sludge Tons/A	Additional Nitrogen	Yield--Grams Sandy Soil 1st Crop	Yield--Grams Sandy Soil 2nd Crop	Yield--Grams Sandy Soil 3rd Crop	Yield--Grams Sandy Soil 4th Crop	Yield--Grams Sandy Soil Mean	Yield--Grams Clay Soil 1st Crop	Yield--Grams Clay Soil 2nd Crop	Yield--Grams Clay Soil 3rd Crop	Yield--Grams Clay Soil 4th Crop	Yield--Grams Clay Soil Mean
1	0	0	2.0	1.5	2.2	1.8	1.88	7.7	2.2	4.2	4.4	4.63
2	50	0	1.7	1.7	2.2	1.5	1.78	1.5	1.7	2.7	3.6	2.35
3	100	0	1.8	2.2	2.3	1.6	1.98	1.3	2.2	2.7	1.3	1.85
4	150	0	1.6	1.9	2.5	1.7	1.93	1.6	2.8	2.9	1.3	2.15
5	200	0	1.5	2.2	2.3	1.6	1.90	1.6	2.5	3.4	1.2	2.18
6	50	25:1	1.4	2.4	4.6	2.4	2.70	2.6	5.6	11.9	5.3	6.35
7	50	100:1	1.7	1.9	2.3	1.8	1.93	1.6	1.8	6.6	4.6	3.65
8	100	25:1	3.1	7.8	5.4	4.0	5.08	5.8	5.9	13.2	6.1	7.75
9	100	100:1	2.0	2.4	2.8	1.3	2.13	1.4	1.6	5.0	6.6	3.65
10	150	25:1	2.0	7.5	7.7	2.7	4.98	5.7	5.5	10.7	4.8	6.68
11	150	100:1	2.0	2.3	2.9	1.9	2.28	1.5	2.0	3.0	7.3	3.45
12	200	25:1	1.9	6.5	10.2	1.9	5.13	5.1	6.6	8.1	4.8	6.15
13	200	100:1	2.2	2.1	2.5	1.1	1.98	1.4	2.3	4.0	6.7	3.60
14	0	(1)	2.5	2.5	5.9	1.2	3.03	5.4	1.0	6.2	5.2	4.45
15	0	(2)	0.4	1.7	4.7	2.6	2.35	4.3	0.8	0.9	1.8	1.95
16	0	(3)	0	1.9	4.0	0	1.48	1.0	0.5	0.5	0	0.50
17	0	(4)	0	0.7	3.0	0	0.93	0	0	1.4	0	0.35

(1), (2), (3) and (4) equivalent nitrogen added in Treatments 6, 8, 10 and 12 respectively.

TABLE VI

TOTAL QUALITY SCORES OF 1970-1972 CORN AND BEAN CROPS ON TOLERANCE AND YEARLY AMENDMENT DESIGN PLOTS

Tolerance Design										Yearly Amendment Design									
		Corn				Beans						Corn				Beans			
Sludge T/A	Nitrogen Addition lbs	Plot No.	70	71	72	Plot No.	70	71	72	Sludge T/A	Nitrogen Addition lbs	Plot No.	70	71	72	Plot No.	70	71	72
0	91.6	1A	0	8	7	5A	1	(1)	3	0	45.8	9A	0	14	0	13A	0	(1)	0
0	18.3	1B	14	16	14	5B	9		10	0	9.2	9B	14	18	19	13B	9		6
0	9.2	1C	15	16	17	5C	11		14	0	4.6	9C	15	15	13	13C	11		10
0	0	1D	18	16	16	5D	17		15	0	0	9D	18	16	15	13D	17		10
	C:N										C:N								
200	10:1	2A	2	18	18	6A	6		6	100	10:1	10A	7	17	14	14A	6		7
200	50:1	2B	16	18	17	6B	12		17	100	50:1	10B	16	19	10	14B	13		14
200	100:1	2C	18	19	17	6C	14		17	100	100:1	10C	19	17	7	14C	16		12
200	0	2D	12	17	16	6D	10		17	100	0	10D	19	12	8	14D	20		6
400	10:1	3A	0	19	18	7A	0		16	200	10:1	11A	2	13	6	15A	6		5
400	50:1	3B	12	19	18	7B	10		17	200	50:1	11B	16	14	4	15B	12		6
400	100:1	3C	16	19	17	7C	12		18	200	100:1	11C	18	14	3	15C	14		6
400	0	3D	9	19	16	7D	9		17	200	0	11D	12	4	2	15D	10		6
600	10:1	4A	0	19	20	8A	0		16	400	10:1	12A	0	10	12	16A	0		11
600	50:1	4B	12	19	20	8B	11		19	400	50:1	12B	12	13	14	16B	10		8
600	100:1	4C	12	19	20	8C	11		19	400	100:1	12C	16	13	13	16C	12		8
600	0	4D	7	19	20	8D	8		18	400	0	12D	9	3	10	16D	9		8

(1) TQS not determined for 1971 crop.

TABLE VII

EFFECT OF CLARIFIER SLUDGE ON CORN YIELD IN FIELD PLOT TOLERANCE STUDIES

Plot No.	Sludge Tons/A	Nitrogen Addition Lbs-N	Pounds Corn			
			1970	1971	1972	3 Years Total
1A	0	91.6	1.9	1.5	12.6	16.0
1B	0	18.3	27.8	20.2	25.7	73.7
1C	0	9.2	33.5	27.3	33.3	94.1
1D	0	0	55.5	26.3	28.4	110.2
		C:N				
2A	200	10:1	0	34.0	30.6	64.6
2B	200	50:1	32.7	44.1	35.0	111.8
2C	200	100:1	69.9	35.0	39.0	143.9
2D	200	0	46.9	34.8	32.7	114.4
3A	400	10:1	0	47.6	41.7	89.3
3B	400	50:1	41.4	52.9	42.8	137.1
3C	400	100:1	47.3	51.5	43.4	142.2
3D	400	0	24.7	47.3	28.9	100.9
4A	600	10:1	0	35.7	50.9	86.6
4B	600	50:1	26.4	46.5	48.6	121.5
4C	600	100:1	34.5	49.3	45.6	129.4
4D	600	0	21.5	46.4	46.8	114.7

TABLE VIII

EFFECT OF CLARIFIER SLUDGE ON BEAN YIELD IN FIELD PLOT TOLERANCE STUDIES

Plot No.	Sludge Tons/A	Nitrogen Addition Lbs-N	Pounds Beans			
			1970	1971	1972	3 Years Total
5A	0	91.6	0	0.3	0.4	0.7
5B	0	18.3	3.1	4.6	8.8	16.5
5C	0	9.2	17.1	13.1	22.2	52.4
5D	0	0	32.2	17.4	17.9	67.5
		C:N				
6A	200	10:1	0.1	0.3	0.8	1.2
6B	200	50:1	5.8	18.4	28.5	52.7
6C	200	100:1	26.1	23.4	31.2	80.7
6D	200	0	21.8	21.2	31.5	74.5
7A	400	10:1	0	1.8	30.1	31.9
7B	400	50:1	1.4	19.3	33.7	54.4
7C	400	100:1	5.0	26.8	30.7	62.5
7D	400	0	7.3	20.1	27.9	55.3
8A	600	10:1	0	2.6	30.5	33.1
8B	600	50:1	2.7	24.4	39.1	66.2
8C	600	100:1	5.4	27.4	42.7	75.5
8D	600	0	2.8	20.1	38.5	61.4

TABLE IX

EFFECT OF CLARIFIER SLUDGE ON CORN YIELD IN FIELD PLOT YEARLY AMENDMENT STUDIES

Plot No.	Sludge Tons/A	1970		1971		1972	
		N-Addition Lbs-N	Lbs-Yield	N-Addition Lbs-N	Lbs-Yield	N-Addition Lbs-N	Lbs-Yield
9A	0	45.8	3.0	18.3	0	18.3	0
9B	0	9.2	29.9	9.2	47.2	9.2	6.9
9C	0	4.6	42.8	4.6	40.3	4.6	32.0
9D	0	0	51.8	0	32.8	0	30.8
		C:N		C:N		C:N	
10A	100	10:1	10.3	50:1	31.6	50:1	37.8
10B	100	50:1	49.1	100:1	40.5	100:1	39.8
10C	100	100:1	52.4	200:1	13.4	200:1	27.5
10D	100	0	55.8	0	0	0	21.4
11A	200	10:1	4.0	50:1	6.4	50:1	6.1
11B	200	50:1	39.3	100:1	6.0	100:1	4.3
11C	200	100:1	47.5	200:1	0.5	200:1	3.1
11D	200	0	54.1	0	0.5	0	2.6
12A	400	10:1	0	50:1	5.8	50:1	32.9*
12B	400	50:1	28.0	100:1	3.7	100:1	28.3*
12C	400	100:1	42.0	200:1	3.6	200:1	35.3*
12D	400	0	27.6	0	1.2	0	27.8*

*Was not possible to add 400 T/A rate for third year. Values not consistent for experimental design.

TABLE X

EFFECT OF CLARIFIER SLUDGE ON BEAN YIELD IN FIELD PLOT YEARLY AMENDMENT STUDIES

Plot No.	Sludge Tons/A	1970		1971		1972	
		N-Addition Lbs-N	Lbs-Yield	N-Addition Lbs-N	Lbs-Yield	N-Addition Lbs-N	Lbs-Yield
13A	0	45.8	0.1	18.3	0	18.3	0
13B	0	9.2	17.9	9.2	7.9	9.2	4.5
13C	0	4.6	33.2	4.6	24.5	4.6	9.2
13D	0	0	37.2	0	22.6	0	27.4
		C:N		C:N		C:N	
14A	100	10:1	0.2	50:1	0.9	50:1	2.1
14B	100	50:1	27.3	100:1	19.0	100:1	19.3
14C	100	100:1	41.4	200:1	15.9	200:1	18.7
14D	100	0	40.3	0	6.7	0	5.3
15A	200	10:1	0	50:1	0.3	50:1	0.6
15B	200	50:1	10.4	100:1	7.5	100:1	1.7
15C	200	100:1	36.0	200:1	8.1	200:1	1.2
15D	200	0	34.3	0	2.1	0	1.8
16A	400	10:1	0	50:1	3.8	50:1	16.0*
16B	400	50:1	1.6	100:1	1.5	100:1	6.1*
16C	400	100:1	4.8	200:1	0.9	200:1	6.7*
16D	400	0	6.0	0	0	0	4.7*

*Was not possible to add 400 T/A rate for third year. Values not consistent for experimental design.

TABLE XI

STRAWBERRY YIELDS UNDER MULCH CONDITIONS--1972 CROP

Treatment	Days Picked--Yield in Ounces											
	6/9	6/12	6/15	6/17	6/19	6/21	6/26	6/29	7/1	7/3	7/5	Total
Control												
Plot 1B	58	50	84	24	77	71	50	18	--	--	--	432
Plot 2C	31	46	106	34	115	142	97	65	12	25	--	673
Plot 4B	38	31	74	43	120	92	98	76	30	43	11	656
Total	127	127	264	101	312	305	245	159	42	68	11	1761
1.5" Layer												
Plot 1A	31	35	85	15	123	84	64	30	--	--	--	467
Plot 2B	16	25	56	19	147	86	99	95	34	37	--	614
Plot 3A	17	26	67	27	98	105	125	73	36	34	--	608
Total	64	86	208	61	368	275	288	198	70	71	--	1689
3.0" Layer												
Plot 2A	7	7	33	8	59	45	42	44	18	26	--	289
Plot 3C	8	21	52	28	95	102	115	92	33	50	--	596
Plot 4C	5	19	49	24	103	69	94	81	37	51	17	549
Total	20	47	134	60	257	216	251	217	88	127	17	1434
5.0" Layer												
Plot 1C	8	9	33	9	78	52	48	46	--	--	--	283
Plot 3B	5	10	33	23	64	67	88	78	40	57	--	465
Plot 4A	2	9	26	18	57	60	67	90	43	48	35	455
Total	15	28	92	50	199	179	203	214	83	105	35	1203

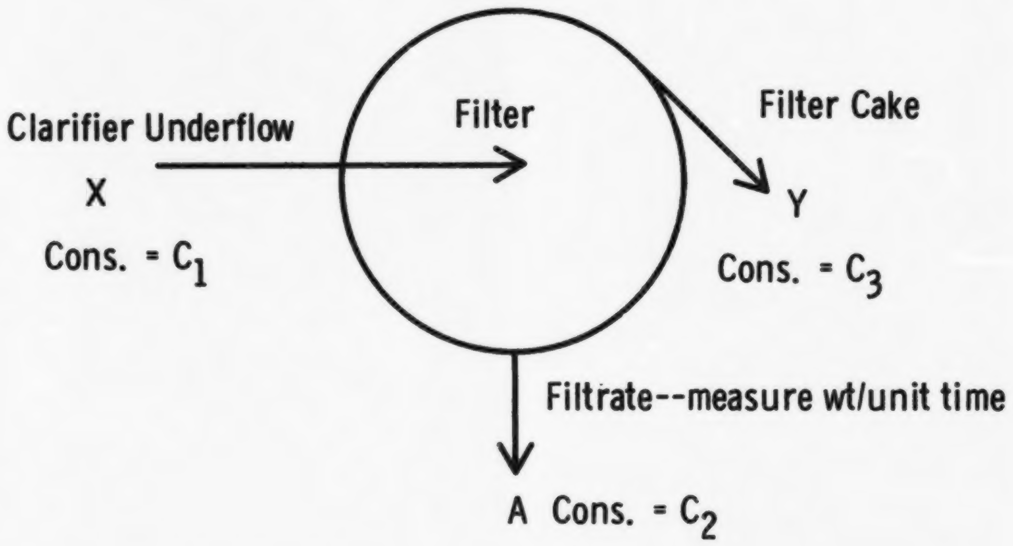
TABLE XII

RASPBERRY YIELDS UNDER MULCH CONDITIONS--1972 CROP

Treatment	Days Picked--Yield in Ounces												
	6/22	6/25	6/28	6/30	7/3	7/5	7/8	7/10	7/13	7/15	7/17	7/21	Total
Control													
Plot 1B	7	12	31	17	35	20	33	11	15	11	11	5	208
Plot 2C	3	5	14	28	28	12	17	12	17	15	19	8	178
Plot 4B	8	14	22	24	31	6	14	8	17	11	9	5	169
Total	18	31	67	69	94	38	64	31	49	37	39	18	555
2" Layer													
Plot 1A	8	10	17	25	32	21	44	18	15	15	26	19	250
Plot 2B	3	4	10	7	8	2	--	--	3	--	--	--	37
Plot 3A	7	10	28	39	46	19	22	23	22	17	25	19	277
Total	18	24	55	71	86	42	66	41	40	32	51	38	564
4" Layer													
Plot 2A	10	13	20	17	38	8	22	13	10	9	7	4	171
Plot 3C	7	9	34	36	56	24	55	28	31	28	26	33	367
Plot 4C	4	11	21	17	27	17	34	15	14	10	15	5	190
Total	21	33	75	70	121	49	111	56	55	47	48	42	728
6" Layer													
Plot 1C	5	8	17	29	27	17	32	8	10	9	13	9	184
Plot 3B	5	8	30	43	67	34	71	30	31	29	50	46	444
Plot 4A	5	11	13	21	37	17	34	12	18	11	17	15	211
Total	15	27	60	93	131	68	137	50	59	49	80	70	839

MATERIAL BALANCE FORMULA

Basic Requirement: Measure all consistencies and one wt/unit time. Example below is for a sludge filter, but could be for a clarifier, press, or dryer.


Clarifier Underflow
X
Cons. = C_1
Filter
Filter Cake
Y
Cons. = C_3
Filtrate--measure wt/unit time
A Cons. = C_2

Let X = Wt. Clarifier flow/unit time
Y = Wt. filter cake/unit time
A = Wt. filtrate/unit time--measured

Total Weight Balance	X	$= Y + A$	
Solids Balance	C_1X	$= C_3Y + C_2A$	
Substituting for X	$C_1(Y + A)$	$= C_3Y + C_2A$	
Solve for Y	Y	$= \dfrac{A\,(C_2 - C_1)}{(C_1 - C_3)}$	All Knowns
and	X	$= Y + A$	

FIGURE 1A

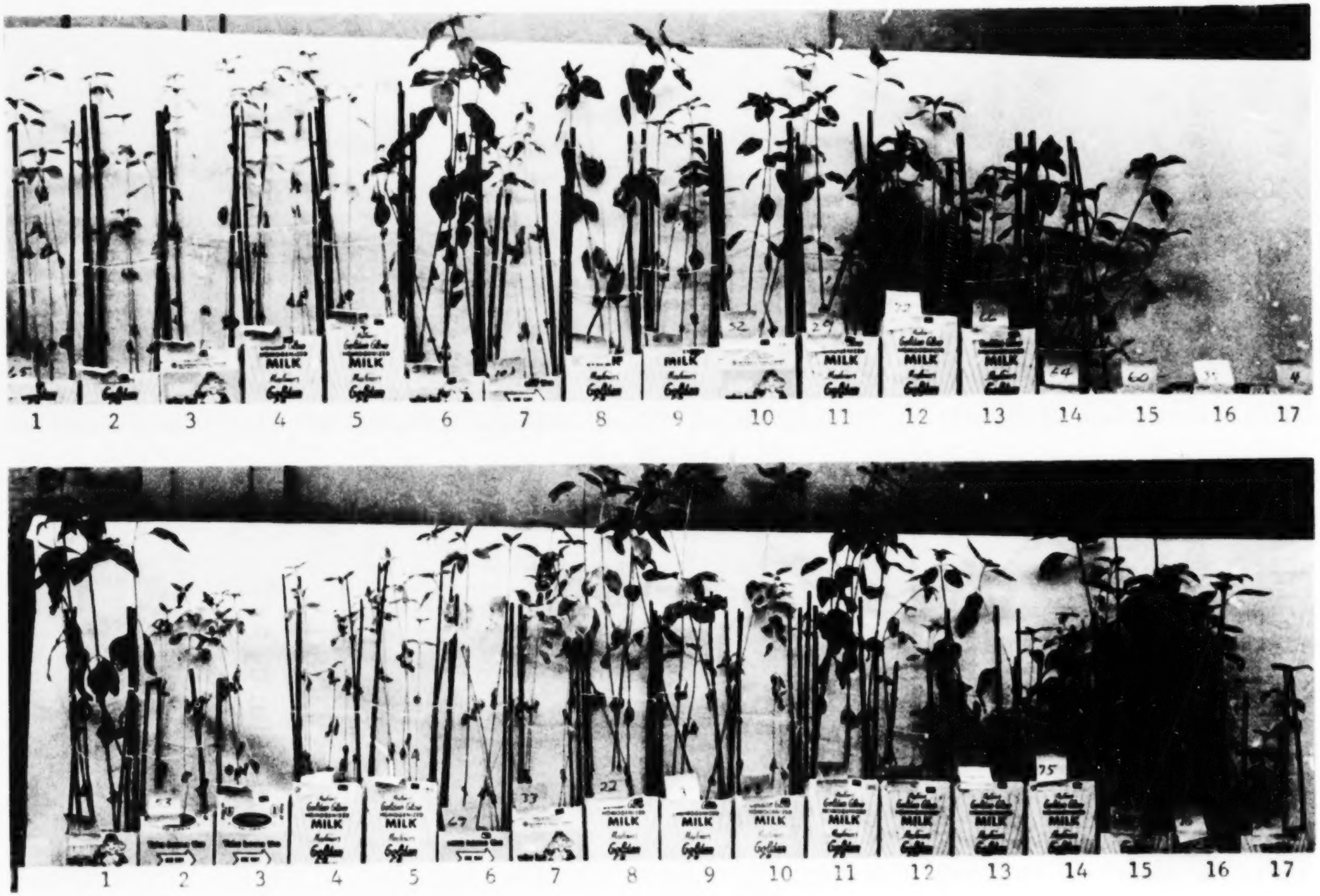

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FIGURE 2A FIRST SUNFLOWER CROP.

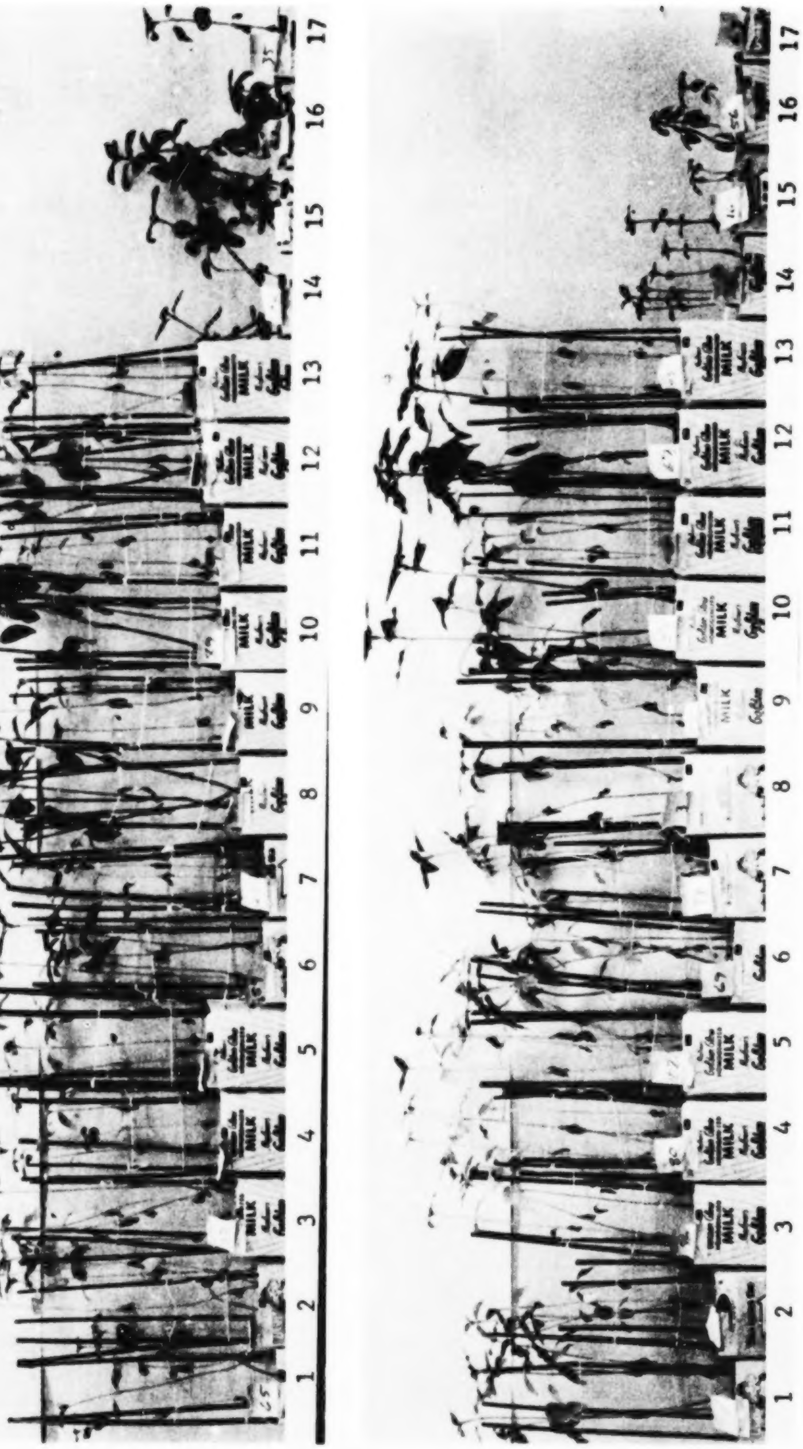
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FIGURE 3A SECOND SUNFLOWER CROP.

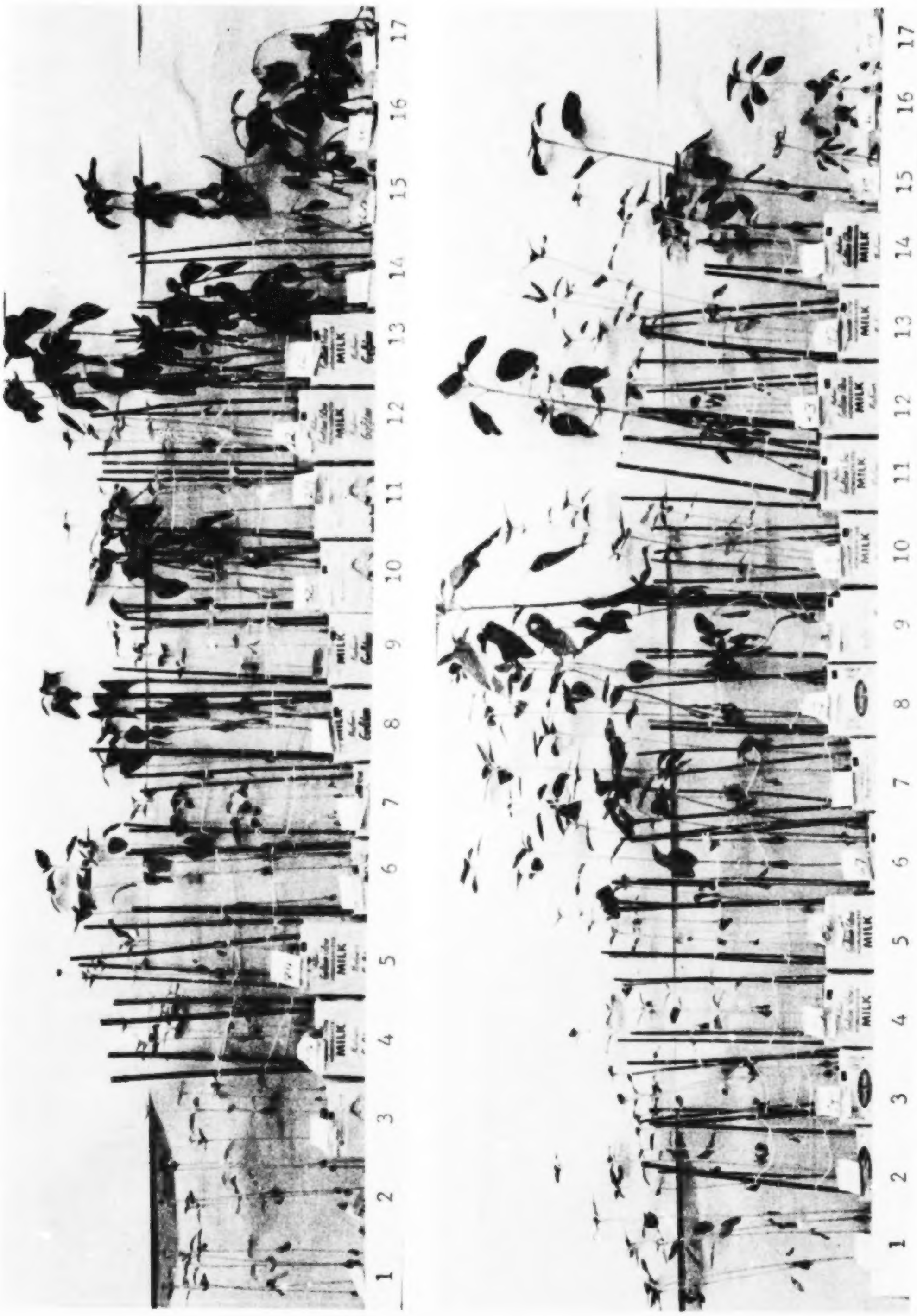
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FIGURE 4A THIRD SUNFLOWER CROP.

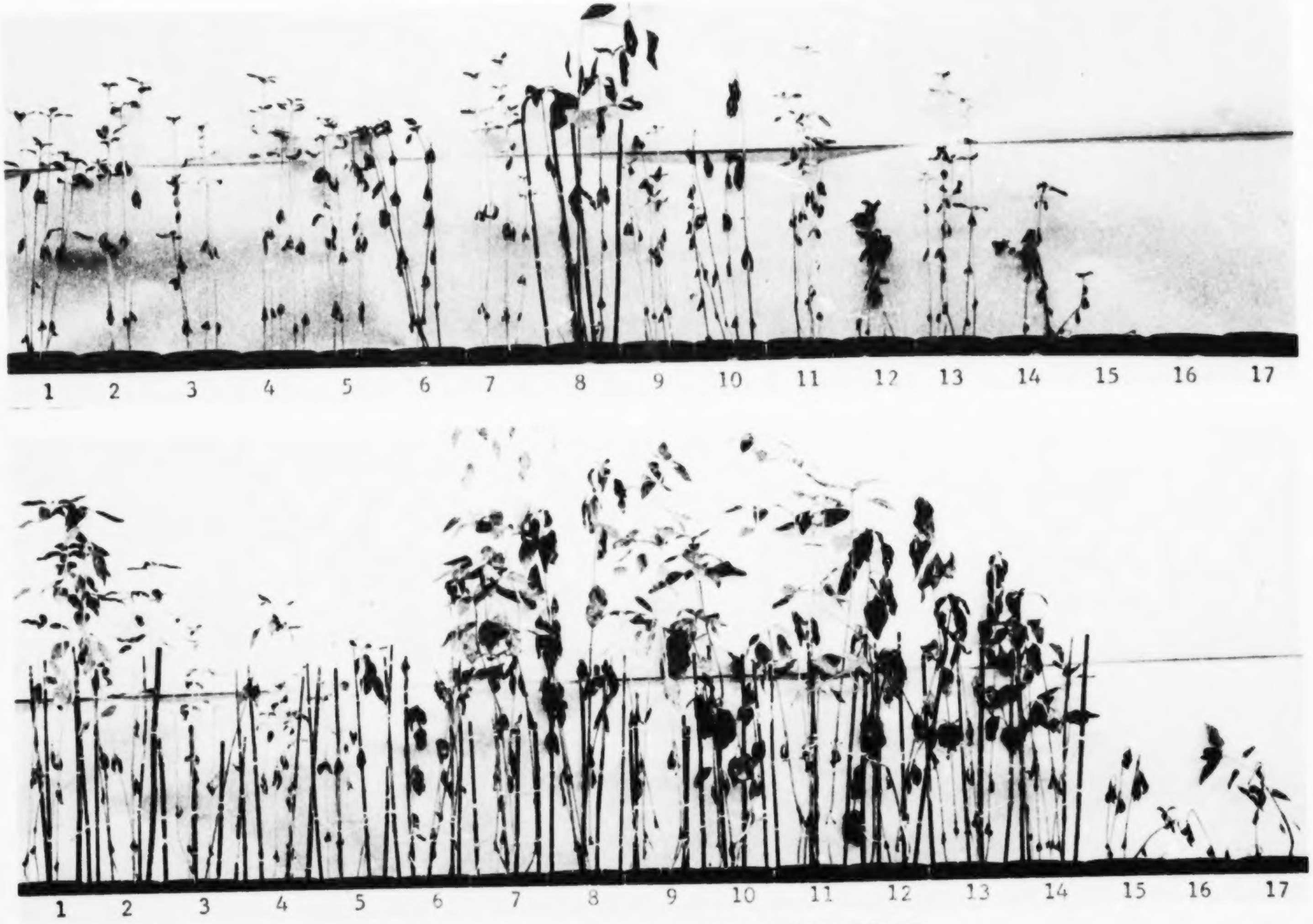
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FIGURE 5A FOURTH SUNFLOWER CROP.